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# MOISTURE RELATIONSHIPS IN SOUTHERN ONTARIO

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In "The Climate of Southern Ontario", Putnam and Chapman (1) described the geographic distribution of the principal climatic elements of temperature and precipitation. The major part of the study was concerned with the temperature factor, although drought frequencies defined on an arbitrary basis were presented for the province, and Thornthwaite's original climatic classification (4) was used to compute the precipitation effectiveness indices for the three summer months. Thornthwaite's new classification (5) introduced a method of assessing the adequacy of precipitation by comparing it with the potential evapotranspiration or water need. In this way, times of water surplus and water deficiency can be determined and quantitatively expressed. An earlier article in this journal, "The climates of Canada according to the new Thornthwaite classification" (2) applied the method to the normals of the Canadian weather stations, and maps were presented of the new climatic elements of water need, water surplus and water deficiency. The same elements are presented on larger scale maps of southern Ontario in the first part of the present study.

Since normals do not express the all-important variability of the moisture factor in climate, the second part of the paper deals with the year-by-year variations in deficiency, surplus and climatic type at four representative stations in the southern part of the province.

## PART I. AVERAGE MOISTURE RELATIONSHIPS

The general precipitation pattern in southern Ontario was presented in the earlier article by Putnam and Chapman (1). Precipitation ranges from 38 in. on the slopes east of Lake Huron and Georgian Bay and in the two eastern counties of Prescott and Glengarry, to less than 26 in. around Collingwood and in the extreme southwest of the province. Manitoulin Island and the Bruce Peninsula, Prince Edward County, the Niagara fruit belt and the Renfrew area annually receive less than 30 in. of precipitation

### *Potential Evapotranspiration*

The concept of potential evapotranspiration or water need, introduced into climatological literature by Thornthwaite, has been discussed in previous publications (2) (3). Monthly or daily water need can be computed by means of a formula from the mean temperature modified by a length of day factor. The theoretical values of water need provided by the formula for southern Ontario have been verified by actual experiment (3). Equipment to measure the daily potential evapotranspiration from a grass-covered surface has been in operation in Toronto for three years and the results, given below, indicate the close correlation between measured water losses and those computed by means of the Thornthwaite formula.

TABLE 1.—POTENTIAL EVAPOTRANSPIRATION (CM.)

| | 1947 | | 1948 | | 1949 | |
|---|---|---|---|---|---|---|
| | Measured | Computed | Measured | Computed | Measured | Computed |
| May | — | — | — | — | 11.2 | 7.9 |
| June | (6 days) 2.6 | 2.9 | (18 days) 8.6 | 7.2 | 16.3 | 14.1 |
| July | 12.4 | 13.0 | 14.8 | 13.4 | 15.0 | 14.8 |
| August | 11.5 | 13.4 | 14.2 | 12.2 | 13.2 | 13.3 |
| September | 8.0 | 8.6 | 9.6 | 9.4 | 6.2 | 7.0 |
| October | 4.0 | 6.1 | 4.8 | 3.7 | 4.4 | 5.5 |
| November | (14 days) 1.0 | 1.0 | 1.6 | 2.2 | (22 days) 1.4 | 1.0 |
| Total | 39.5 | 45.0 | 53.6 | 48.1 | 67.7 | 63.6 |

(The monthly totals represent the summation of the daily readings in each case.)

The annual potential evapotranspiration has been computed for the 83 weather stations in southern Ontario and its geographic distribution presented in Figure 1. These figures of water need express the amount of water annually needed for growth by the vegetation in each locality. They are also heat indices since they are derived from the mean monthly temperatures and take into consideration the varying lengths of day throughout the growing season. Potential evapotranspiration is thus a better expression of thermal efficiency than Thornthwaite's earlier, empirical T-E index (4), or an index of degree-days which expresses neither the increased growth at higher temperatures nor variation in day length.

Water needs of more than 25 in. per year are characteristic of Kent and Essex at the southwest tip of the province, and explain the great diversity of crops which can be grown there. With the exception of the interior valleys of southern British Columbia, water needs in that area are the highest in Canada. The average value of 26.7 in. for Pelee Island is the second highest in the Dominion. The western end of Lake Ontario and the Niagara fruit belt have similar high water needs of over 24 in., while the highlands east of Lake Huron and the Algonquin Park uplands have the lowest needs in southern Ontario, of less than 22 in. The heavy dashed line in Figure 1, representing a water need of 22.4 in., is an important boundary in the Thornthwaite classification, between the warmer mesothermal and cooler microthermal climatic types. The area which lies to the south of this line in Ontario, belonging to the mesothermal region, is the largest continuous area in Canada so climatically favoured.

*Water Surplus and Deficiency*

A figure of average annual water surplus can be obtained by applying the Thornthwaite formula to climatic data, and a further proof of the formula was supplied by the close correlation found to exist between computed water surplus and the measured run-off in the streams of southern Ontario (3). Water surplus is the result of precipitation in excess of need after the soil moisture has been replenished. It cannot be utilized by the vegetation since it runs off the surface or percolates through the soil to the ground water table. Figure 2 shows the distribution of average water

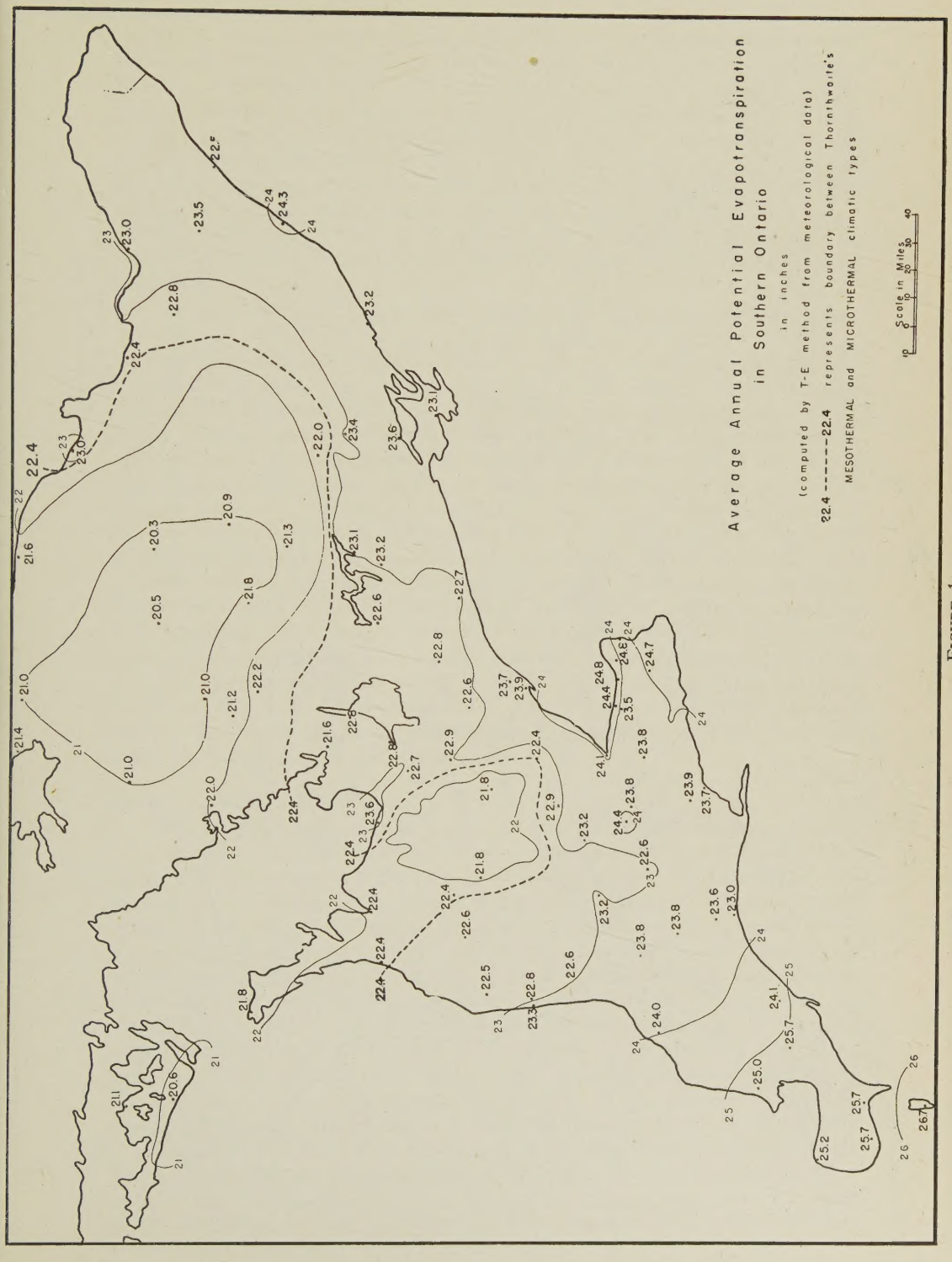
Average Annual Potential Evapotranspiration
in Southern Ontario
in inches
(computed by T-E method from meteorological data)
22.4 ------ 22.4 represents boundary between Thornthwaite's
MESOTHERMAL and MICROTHERMAL climatic types
Scale in Miles
0 10 20 30 40

FIGURE 1

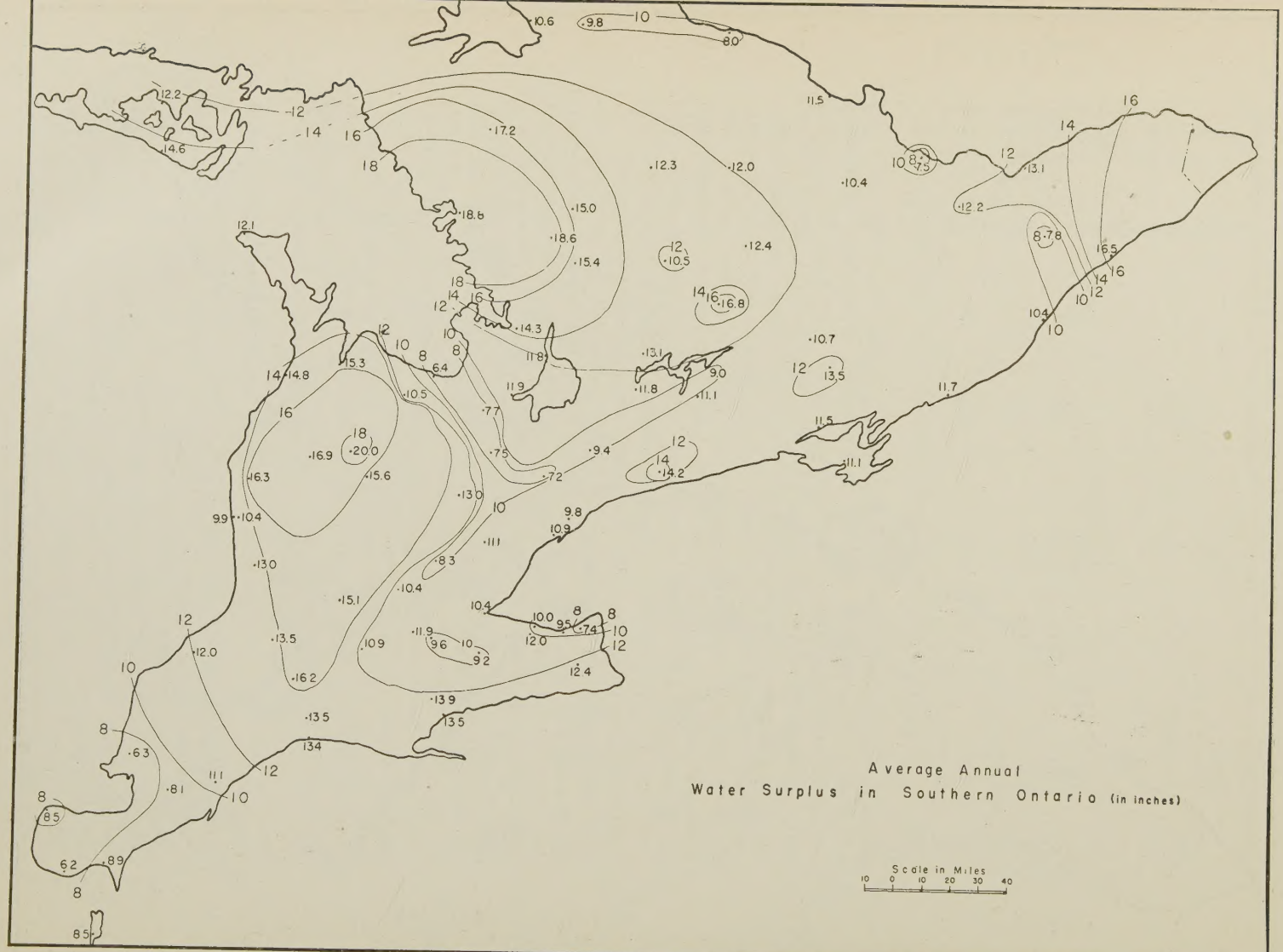
Average Annual
Water Surplus in Southern Ontario (in inches)
Scale in Miles
10 0 10 20 30 40

FIGURE 2

surplus in southern Ontario. Large surpluses of over 16 in. are characteristic of the area east of Georgian Bay, around Walkerton, Durham and Teeswater in Grey and Bruce counties, and in the eastern counties of Prescott and Glengarry. The Lake St. Clair-Harrow area and the St. Catharines region have small average surpluses of less than 8 in. A large average water surplus is not beneficial to the soil since it annually removes needed nutrients beyond the range of the plant roots. Large surpluses also make farming operations difficult and costly, by keeping the ground muddy and intractable in spring, delaying sowing operations and necessitating drainage. However, a surplus is agriculturally important in recharging ground water supplies and providing water for live stock and irrigation.

In most climatic classifications, southern Ontario has a humid climate, yet this fact does not exclude the possibility of drought. When the potential evapotranspiration exceeds the supply of moisture in the soil, moisture deficiency or drought occurs. The normal distribution of deficiency is shown in Figure 3. The west-central counties, the eastern tip of the province and the Algonquin Park uplands have average deficiencies of less than 1 in. Regions with deficiencies of more than 4 in. include Kent and Essex counties, the Prince Edward peninsula and the area below the escarpment in the Niagara peninsula. According to the Thornthwaite formula, 10 cm. or 4 in. is the amount of water available to the vegetation in the normal soil, and the above computed figures of deficiency were based on that assumption. However, there are some Ontario soils which could not hold 4 in.; and some which undoubtedly hold more than the 4 in. average. The shallow limestone soils of the Napanee plain, Prince Edward county, Manitoulin Island and the Bruce peninsula, belonging to the former group, thus probably suffer higher deficiencies than those shown in Figure 3; while deep black clay loams, such as those in Kent county, belong to the latter group, and actual deficiencies are doubtless lower than those shown in Figure 3.

*Actual Evapotranspiration*

The evapotranspiration or water loss that actually occurs in an average or a specific year can be computed from the meteorological statistics by using the Thornthwaite formula. Figure 4 shows the distribution of average actual evapotranspiration in southern Ontario. Actual evapotranspiration means potential evapotranspiration less water deficiency. Thus high water needs and low deficiencies characterize the areas where actual water losses are greatest, and, from the combined heat and moisture point of view, climatically best suited to agriculture. Highest average water losses occur in the Brantford, Woodstock, Stratford, and London region, and in the extreme east of the province, enclosed by the 22 in. isopleth (Figure 4). Harrow, with a high potential evapotranspiration of 26.7 in. has an actual water loss of only 19 in. in the average year. The lowest actual evapotranspiration in southern Ontario occurs on Manitoulin Island, where relatively low water need is combined with high deficiency. Since Figure 4 shows the geographic distribution of actual evapotranspiration, or the total water loss occurring during the average growing season, it best suits the purposes of correlation with yields of crops such as pasture grasses, whose growth is not affected by differences in planting dates.

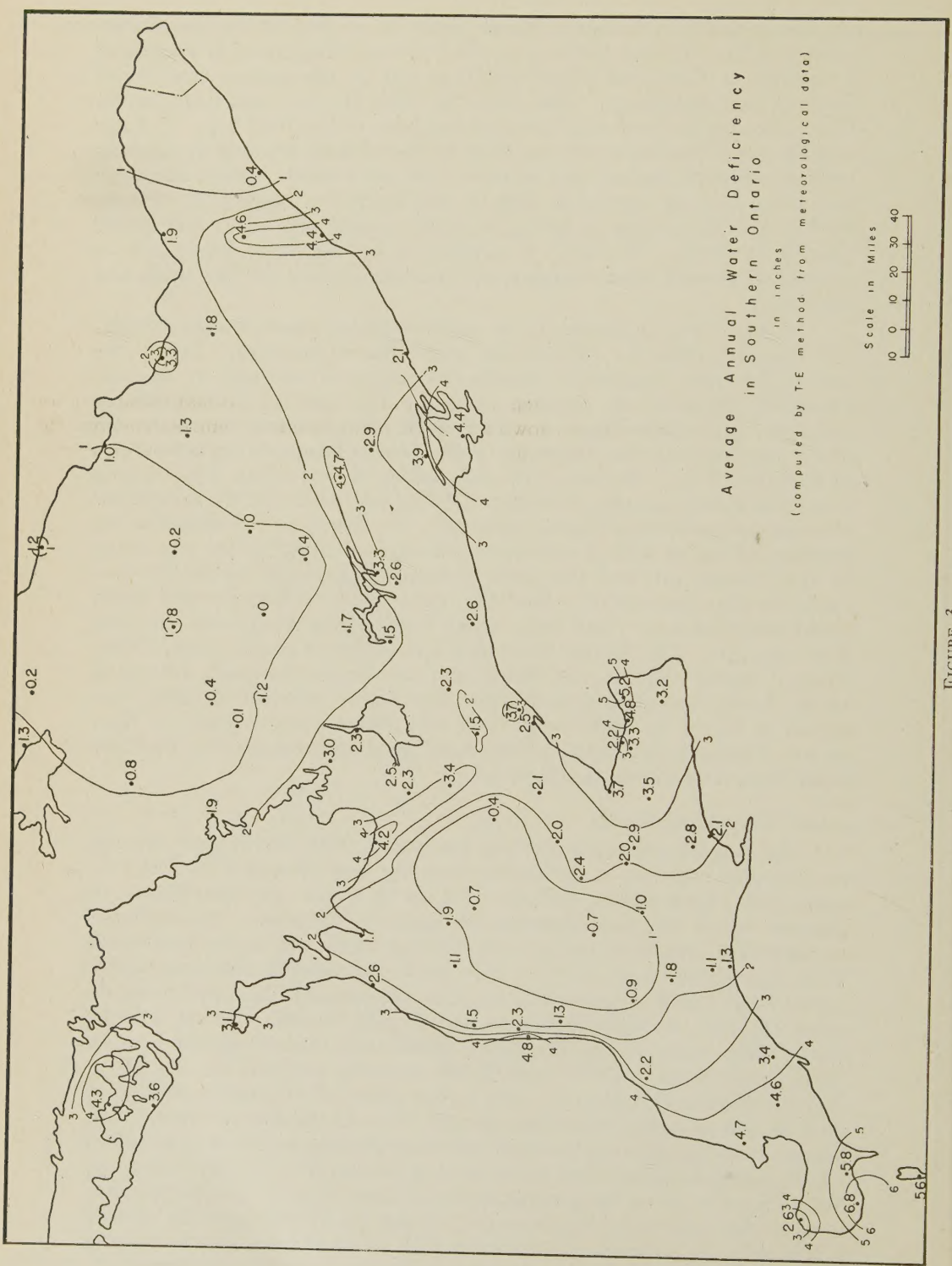
Average Annual Water Deficiency
in Southern Ontario
in inches
(computed by T-E method from meteorological data)
Scale in Miles
10 0 10 20 30 40

FIGURE 3

*A Moisture Index*

To satisfy the need for a rational climatic classification, Thornthwaite has devised a moisture index, relating water surplus and deficiency to need, on the following basis:

$$i = \frac{\text{surplus} - 0.6\ \text{deficiency}}{\text{need}}$$

For example, Toronto with a surplus of 10.9 in., a deficiency of 2.5 in., and a water need of 23.9 in., has an index of 39.3.

The Thornthwaite indices and corresponding climatic types appear below:

| Symbol | Climatic type | Moisture index | Symbol | Climatic type | Moisture index |
|---|---|---|---|---|---|
| A | Perhumid | 100 + | $C_2$ | Moist subhumid | 0 to 20 |
| $B_4$ | Humid | 80 to 100 | $C_1$ | Dry subhumid | 0 to −20 |
| $B_3$ | Humid | 60 to 80 | D | Semi-arid | −20 to −40 |
| $B_2$ | Humid | 40 to 60 | E | Arid | −40 to −60 |
| $B_1$ | Humid | 20 to 40 | | | |

All nine moisture provinces in the Thornthwaite classification are found in Canada, although only five are represented in southern Ontario (see Figure 5). There are no areas of the perhumid A climates, found on the Pacific coast, nor do the three driest types $C_1$, D and E, characteristic of Western Canada and the interior valleys of British Columbia, appear in southern Ontario. All four humid climatic types, $B_4$, $B_3$, $B_2$, and $B_1$ appear in Figure 5 as well as the moist subhumid $C_2$ type. Beatrice is the most humid station, with an index of 87.5; Harrow the least humid, with an index of 8.4. This wide range in moisture conditions is illustrated by the fact that Charlottetown, P.E.I., has a moisture index of 85.4, while Sprague near Winnipeg, Manitoba (index 1.5) and Banff, Alberta (index 6.5) have moisture conditions similar to those at Harrow. Three areas are characterized by moist subhumid climates—Kent and Essex counties, the Collingwood area and the tip of the Niagara peninsula, while the most humid $B_4$ type is found in the areas with greatest surplus—east of Georgian Bay and in western Ontario around Durham. Graphs of five stations, representing each of the moisture provinces in southern Ontario, appear in Figure 6, and their comparative moisture data are given in Table 2.

TABLE 2

| Moisture province | Station | Precipitation | Potential evapotranspiration | Actual evapotranspiration | Water surplus | Water deficiency | P. E. index |
|---|---|---|---|---|---|---|---|
| | | (inches) | (inches) | (inches) | (inches) | (inches) | |
| Moist subhumid | Harrow | 25.1 | 25.7 | 18.9 | 6.2 | 6.8 | 8.4 |
| Humid $B_1$ | Guelph | 29.3 | 22.9 | 20.9 | 8.3 | 2.0 | 31.3 |
| Humid $B_2$ | Ottawa | 34.2 | 23.0 | 21.1 | 13.1 | 1.9 | 52.0 |
| Humid $B_3$ | Walkerton | 38.4 | 22.6 | 21.5 | 16.9 | 1.1 | 71.9 |
| Humid $B_4$ | Beatrice | 39.6 | 21.2 | 21.1 | 18.6 | 0.1 | 87.5 |

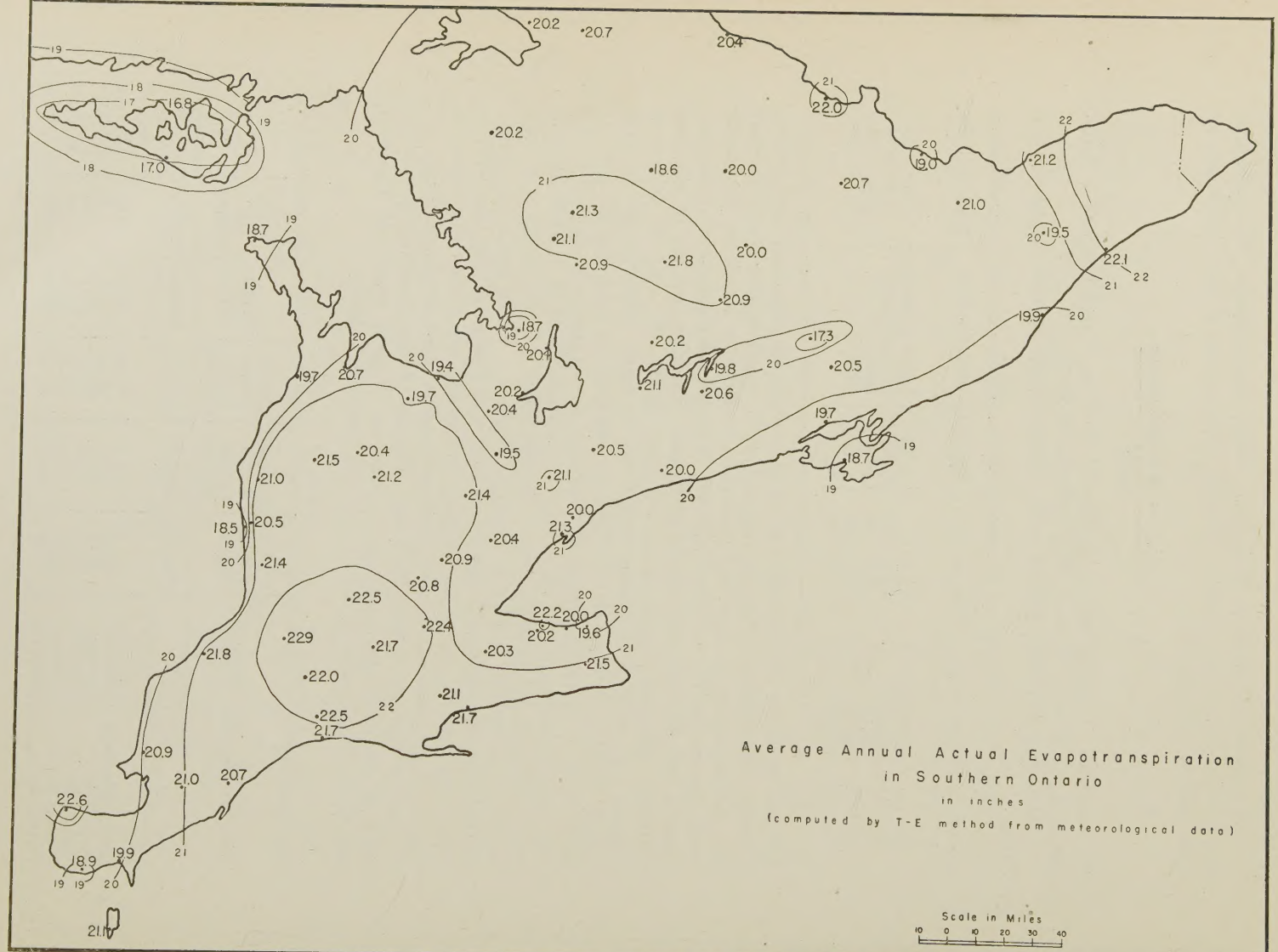
Average Annual Actual Evapotranspiration
in Southern Ontario
in inches
(computed by T-E method from meteorological data)
Scale in Miles
10 0 10 20 30 40

FIGURE 4

Moisture deficiencies steadily decrease and surpluses increase in Table 2 and Figure 6 from subhumid Harrow to most humid Beatrice. There is also a difference of approximately 4 in. in the annual water need between the least humid and the most humid station.

## PART II. VARIABILITY OF MOISTURE

*Method Used*

While it is essential to know the average water relationships at any station, it is equally important to know the deviations from the normal conditions. Rainfall and water need vary from year to year as well as from place to place. To determine the frequencies of moisture deficiencies and surpluses of varying intensities, a study of daily moisture conditions was made at four selected stations for the 26-year period 1923 to 1948. Walkerton, Ottawa, Guelph and Harrow were chosen, since they represent the four major climatic zones; Harrow, Guelph and Ottawa have the additional advantage of being experiment stations. Correlations with actual crop data will thus be facilitated.

The Thornthwaite formula permits the computation of daily as well as monthly evapotranspiration, and by a simple bookkeeping procedure, treating precipitation as income and daily water need as outgo, the changes in soil moisture throughout the season can be determined. Figure 7 illustrates the soil moisture changes during 1948 in Harrow, assuming 10 cm. or 4 in. of moisture available in the soil for plant use. Moisture in excess of this is considered surplus and when the reserve is exhausted drought conditions are assumed.

It can be stated without exception that the soil in southern Ontario is everywhere saturated in early spring. Throughout January, February and March of 1948 at Harrow, precipitation greatly exceeded need, and since the soil moisture had been recharged the previous autumn, a moisture surplus of 14.2 cm. (5.6 in.) resulted (Figure 7). During April, the daily potential evapotranspiration totalled 5.6 cm. but 8.4 cm. of precipitation fell and at the end of the month the soil was still in a saturated condition. In early May, heavy rains resulted in more run-off, but after mid-May the soil began to dry out. By the end of May, the soil moisture level stood at 6.1 cm. During June, the moisture entering the soil from precipitation (11.2 cm.) was almost sufficient to supply the potential evapotranspiration needs (12.2 cm.) and the soil moisture fell slightly. In early July high water needs coupled with scant precipitation caused a rapid fall in soil moisture and by July 12 the moisture reserve was exhausted. The period of drought beginning July 12 lasted until August 9 with little relief. Water deficiency during this period totalled 7.9 cm. (3.1 in.). Again on August 26, the moisture level fell to 0 and the soil remained dry until September 5. A third period of deficiency began on September 15 and ended September 29. During October and November, current precipitation more than satisfied the needs of the vegetation and the reserve of moisture was again built up in the soil. The moisture deficiency for the growing season totalled 15.5 cm. (6.1 in.). This is below the average deficiency of 6.8 in. for Harrow and represents a year with better than average moisture conditions.

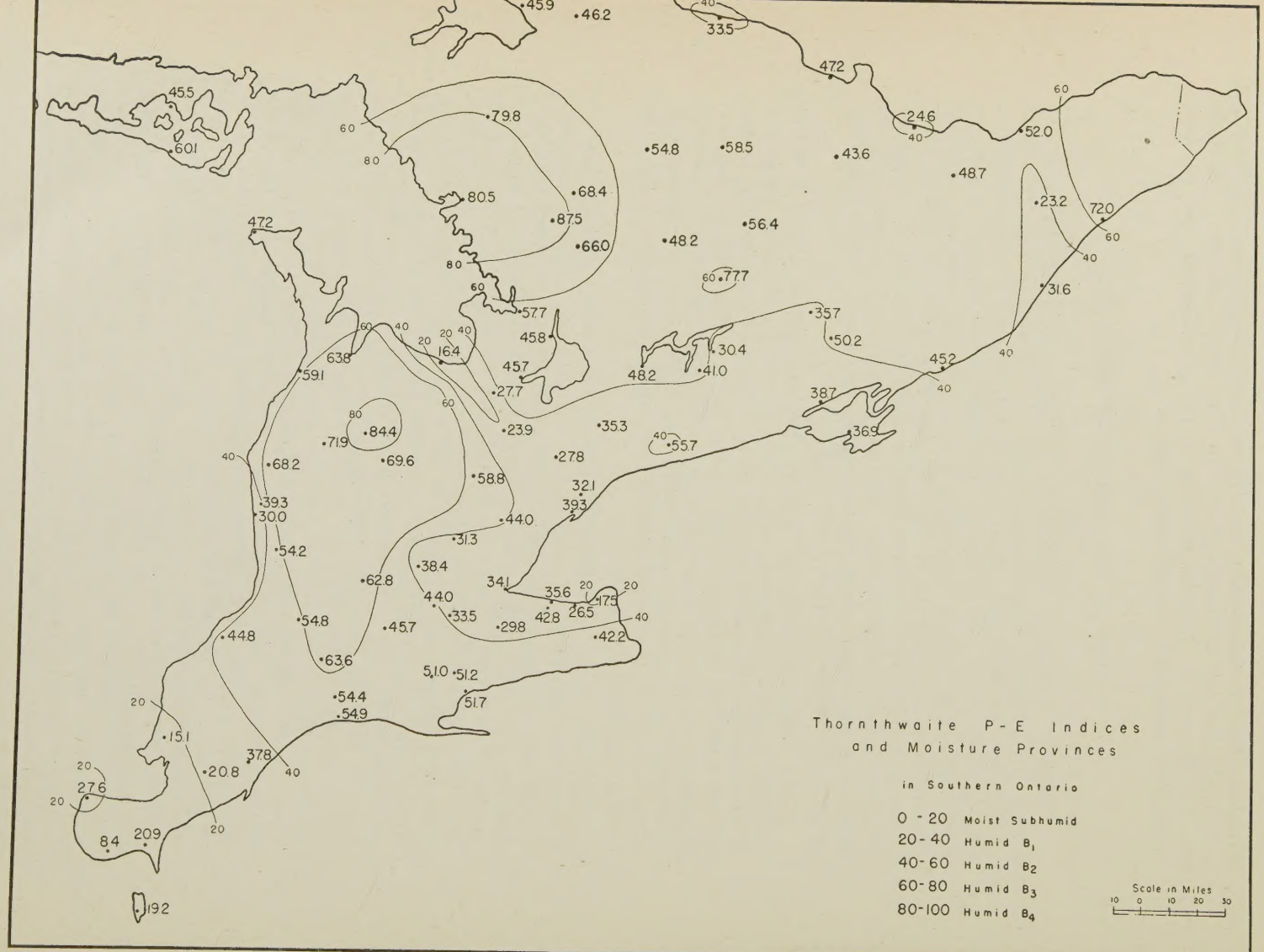
Thornthwaite P-E Indices
and Moisture Provinces
in Southern Ontario
0 - 20 Moist Subhumid
20 - 40 Humid B1
40 - 60 Humid B2
60 - 80 Humid B3
80 - 100 Humid B4
Scale in Miles
10 0 10 20 30

FIGURE 5

*Variations in Precipitation and Water Need*

The annual precipitation at each of the stations for the 26-year period is shown in Table 3, and a considerable variation is revealed. At Harrow the range was greatest, with a minimum in 1933 of 15.0 in. and a maximum in 1937 of 39.1 in. At Guelph, the precipitation ranged from 24.6 in. in 1930 to 41.9 in. in 1926. At Ottawa a maximum precipitation of 42.5 in. occurred in 1943 and a minimum of 24.3 in. in 1931. Walkerton's maximum for the period was 54.4 in. in 1928, the minimum 28.1 in. in 1944.

TABLE 3.—ANNUAL PRECIPITATION (IN INCHES), 1923-1948

| | Harrow | Guelph | Ottawa | Walkerton |
|---|---|---|---|---|
| 1923 | 27.07 | 35.84 | 36.44 | — |
| 1924 | 24.05 | 33.03 | 33.88 | — |
| 1925 | 26.71 | 33.70 | 37.22 | 36.82 |
| 1926 | 37.38 | 41.96 | 33.61 | — |
| 1927 | — | 37.05 | 40.28 | 36.78 |
| 1928 | 17.93 | 34.25 | 41.39 | 54.45 |
| 1929 | 26.15 | 34.24 | 34.85 | 43.64 |
| 1930 | 13.17 | 24.56 | 27.15 | 30.05 |
| 1931 | 17.56 | 31.28 | 24.30 | 33.47 |
| 1932 | 19.98 | 37.22 | 34.92 | 48.17 |
| 1933 | 14.96 | 27.71 | 34.34 | 34.97 |
| 1934 | 21.16 | 29.91 | 32.98 | 30.44 |
| 1935 | 28.40 | 27.63 | 29.49 | 32.05 |
| 1936 | 26.49 | 29.23 | 38.61 | 41.11 |
| 1937 | 39.06 | 36.11 | 37.04 | 38.52 |
| 1938 | 36.20 | 34.45 | 33.61 | 33.90 |
| 1939 | 29.54 | 25.70 | 37.47 | 39.65 |
| 1940 | 33.58 | 40.41 | 30.78 | — |
| 1941 | 27.89 | 28.39 | 29.70 | 33.51 |
| 1942 | 31.94 | 41.38 | 34.37 | 40.33 |
| 1943 | 28.68 | 30.96 | 42.50 | 38.75 |
| 1944 | 22.40 | 30.90 | 25.87 | 28.14 |
| 1945 | 31.97 | 40.84 | 40.59 | 38.62 |
| 1946 | 18.61 | 25.17 | 40.61 | — |
| 1947 | 32.79 | 32.44 | 40.06 | — |
| 1948 | 32.25 | 29.69 | 33.03 | — |
| | | | | 1921—34.14 |
| | | | | 1922—36.24* |

* 1921 and 1922 used for Walkerton to compensate for gaps in study period.

While the variation in precipitation was great from year to year, the variation in potential evapotranspiration or water need was relatively small. The annual water need at Harrow, obtained as the sum of the daily water needs, varied from 30.5 in. in 1941 to 24.1 in. in 1924. At Guelph, 1941 again had the highest need of 26.1 in., 1924 the lowest of 21.8 in. The thermal range at Ottawa was similar to that at Guelph during the 26-year period, although the times of maximum and minimum were different. The highest potential evapotranspiration of 26.3 in. occurred here in 1923, the lowest of 21.9 in. in 1926. Walkerton with a shorter period of observation recorded a maximum of 26.5 in. in 1938 and a minimum of 22.9 in. in 1922.

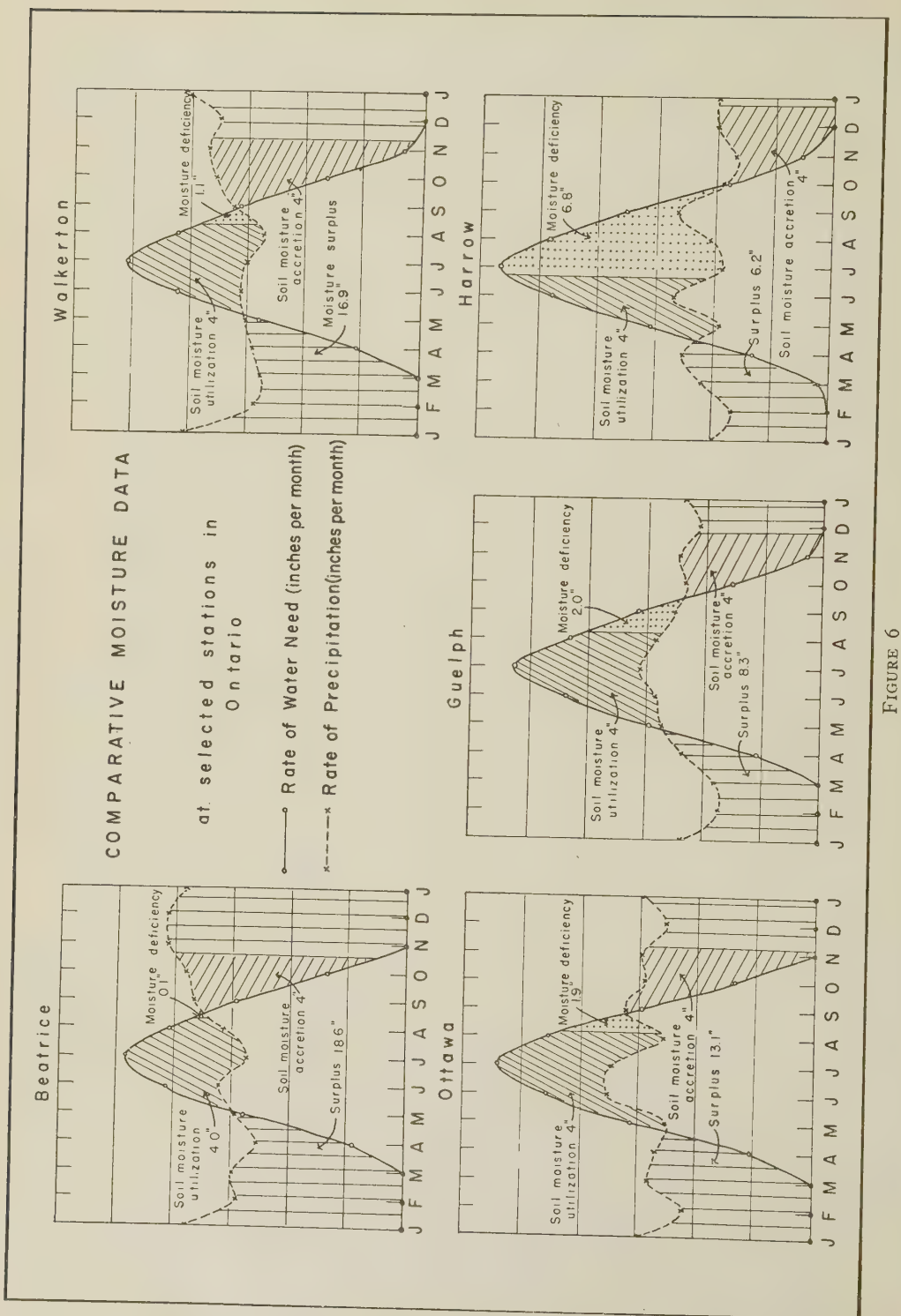
COMPARATIVE MOISTURE DATA
at selected stations in Ontario
Rate of Water Need (inches per month)
Rate of Precipitation (inches per month)
Walkerton
Moisture deficiency 1.1"
Soil moisture utilization 4"
Soil moisture accretion 4"
Moisture surplus 16.9"
Harrow
Moisture deficiency 6.8"
Soil moisture utilization 4"
Surplus 6.2"
Soil moisture accretion 4"
Guelph
Moisture deficiency 2.0"
Soil moisture utilization 4"
Soil moisture accretion 4"
Surplus 8.3"
Ottawa
Moisture deficiency 1.9"
Soil moisture utilization 4"
Soil moisture accretion 4"
Surplus 13.1"
Beatrice
Moisture deficiency 0.1"
Soil moisture utilization 4.0"
Soil moisture accretion 4"
Surplus 18.6"
J F M A M J J A S O N D J

FIGURE 6

*Variations in Deficiency*

The Thornthwaite method as illustrated above for Harrow was used to determine the times and amounts of moisture deficiencies at each of the four stations during the 26-year period. The yearly deficiencies, obtained by totalling the daily values, appear in chronological order in Table 4, while Table 5 illustrates the frequency of occurrence of deficiencies of varying intensities, by 2 in. intervals.

TABLE 4.—MOISTURE DEFICIENCIES (IN INCHES), 1923-1948

| | Harrow | Guelph | Ottawa | Walkerton |
|---|---|---|---|---|
| 1923 | 7.80 | 0.70 | 4.04 | 5.64 |
| 1924 | 5.84 | 0.48 | 3.46 | — |
| 1925 | 7.61 | 1.87 | 3.96 | 4.58 |
| 1926 | 4.20 | 0.08 | 2.51 | — |
| 1927 | 9.35 | 2.15 | 1.89 | 3.43 |
| 1928 | 9.81 | 0 | 0 | 0 |
| 1929 | 9.34 | 5.96 | 3.12 | 5.31 |
| 1930 | 14.58 | 6.88 | 3.41 | 5.79 |
| 1931 | 12.90 | 4.06 | 9.20 | 3.84 |
| 1932 | 10.66 | 0.41 | 3.61 | 1.34 |
| 1933 | 16.21 | 8.35 | 5.78 | 8.64 |
| 1934 | 13.60 | 5.99 | 5.29 | 9.84 |
| 1935 | 5.40 | 4.72 | 3.23 | 4.00 |
| 1936 | 9.54 | 7.86 | 2.74 | 4.78 |
| 1937 | 1.53 | 0.79 | 2.82 | 4.45 |
| 1938 | 5.48 | 3.45 | 1.61 | 4.61 |
| 1939 | 7.62 | 9.22 | 1.34 | 1.13 |
| 1940 | 0.28 | 0.08 | 6.34 | — |
| 1941 | 6.57 | 5.87 | 8.48 | 8.27 |
| 1942 | 5.79 | 3.34 | 5.73 | 4.93 |
| 1943 | 7.02 | 3.02 | 0 | 1.27 |
| 1944 | 14.11 | 3.08 | 10.32 | 7.80 |
| 1945 | 6.29 | 3.15 | 1.61 | 2.74 |
| 1946 | 13.10 | 4.18 | 1.58 | — |
| 1947 | 7.30 | 5.68 | 3.10 | — |
| 1948 | 6.08 | 5.80 | 5.75 | — |
| | | | | 1921—3.48 |
| | | | | 1922—1.06 |

TABLE 5.—NUMBER OF YEARS WITH DEFICIENCIES OF VARYING INTENSITIES

| Deficiency (inches) | Harrow | Guelph | Ottawa | Walkerton |
|---|---|---|---|---|
| 0 | 0 | 1 | 2 | 1 |
| 0 – 1.9 | 2 | 7 | 5 | 4 |
| 2 – 3.9 | 0 | 6 | 10 | 4 |
| 4 – 5.9 | 5 | 8 | 5 | 9 |
| 6 – 7.9 | 8 | 2 | 1 | 1 |
| 8 – 9.9 | 4 | 2 | 2 | 3 |
| 10 – 11.9 | 1 | 0 | 1 | 0 |
| 12 – 13.9 | 3 | 0 | 0 | 0 |
| 14 – 15.9 | 2 | 0 | 0 | 0 |
| 16 – 17.9 | 1 | 0 | 0 | 0 |
| Number of years' record | 26 | 26 | 26 | 22 |

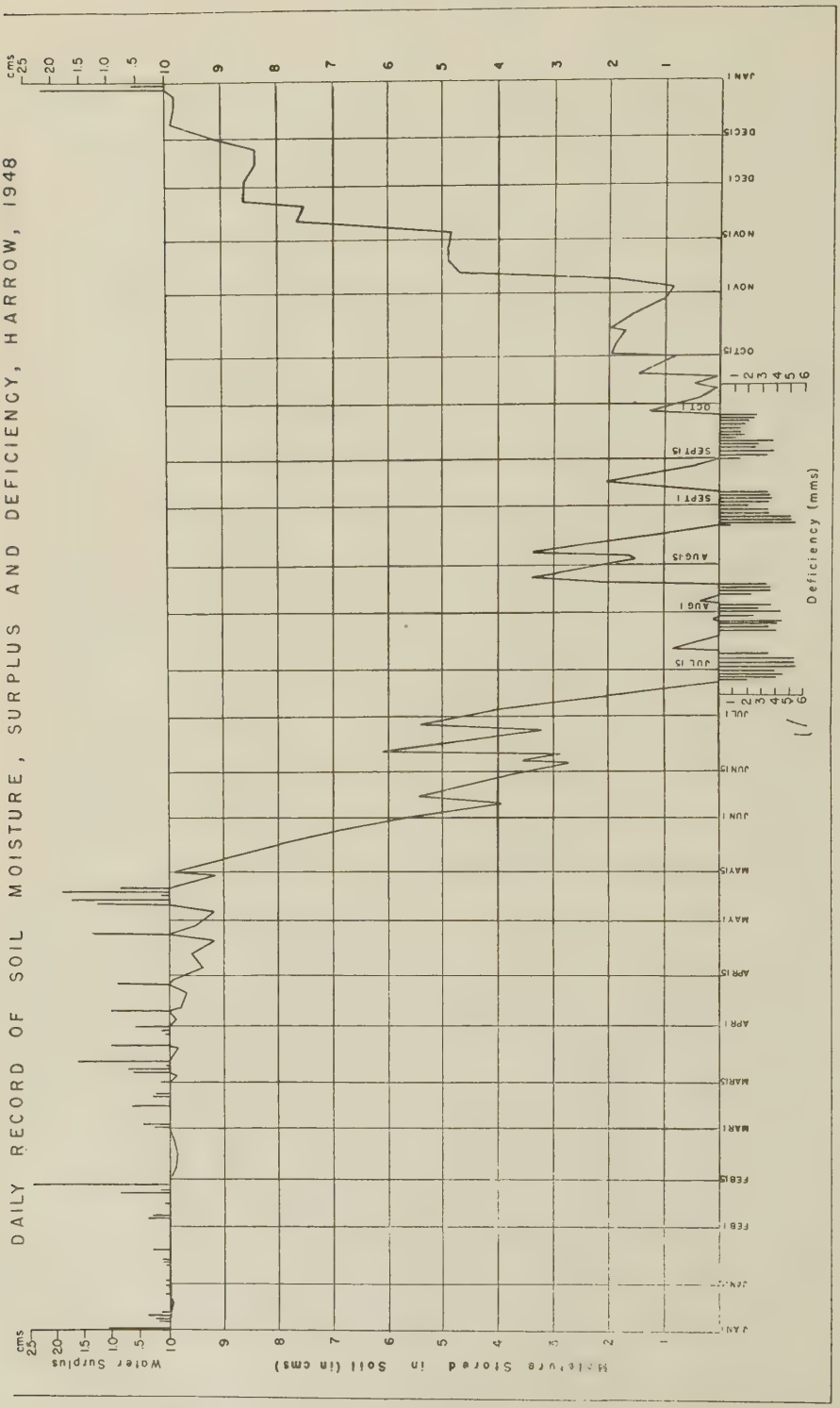
DAILY RECORD OF SOIL MOISTURE, SURPLUS AND DEFICIENCY, HARROW, 1948
Water Surplus
Moisture Stored in Soil (in cms)
Deficiency (mms)
cms
JAN 1
DEC 15
DEC 1
NOV 15
NOV 1
OCT 15
OCT 1
SEPT 15
SEPT 1
AUG 15
AUG 1
JUL 15
JUL 1
JUN 15
JUN 1
MAY 15
MAY 1
APR 15
APR 1
MAR 15
MAR 1
FEB 15
FEB 1

FIGURE 7

A deficiency of moisture is always harmful to a crop, in reducing the yield and making the plant susceptible to disease. Walkerton, the most humid of the four stations, nevertheless had deficiencies ranging from 0 in 1928 to 9.8 in. in 1934. In 9 of the 22 years of record (see Table 5) total deficiencies amounted to less than 4 in., while only 4 years had deficiencies of more than 6 in. The average value was 4.4 in. for the study period, although the long-time average computed on a monthly basis was only 1.1 in. The fact that the long-term average deficiency at all four stations was lower than the 26-year deficiency based on daily values is an indication that the Thornthwaite formula used on a monthly basis underestimates moisture deficiency. The monthly basis cannot give an accurate value of deficiency since it fails to reflect the short droughts that occur within the month. This is the reason why it is necessary to make the daily computations.

Ottawa, representing the less humid $B_2$ climate, had an average deficiency of 3.9 in. during the 26-year period although on a monthly basis the average deficiency was 1.9 in. Deficiencies here ranged from 0 in 1928 and 1943 to 10.3 in. in 1944. Table 5 shows that the deficiency distribution at Ottawa has a well-defined peak in the 2 to 4 in. class. Of the four stations, Ottawa also had the greatest number of years (2) with no deficiency.

Guelph, with a less humid climate than Ottawa, had a similar deficiency distribution with a maximum of 9.2 in. in 1939. During the 26 years annual droughts averaged 3.7 in., while on a monthly basis the long-term average was 2.0 in. At Guelph, deficiencies of 0 to 2 in., 2 to 4 in. and 4 to 6 in. occurred with similar frequency and together accounted for 21 of the 26 years of record. For all 3 humid stations, Walkerton, Ottawa and Guelph, the frequency curve of deficiency is similar.

Harrow, representing the subhumid climatic type in southern Ontario, has deficiencies which may seem surprisingly high to those who consider Ontario a humid area. Here deficiencies varied from 0.3 in. in 1940, to as much as 16.2 in. in 1933. The average value for the 26-year period was 8.4 in. although on a monthly basis the average was 6.8 in. Table 5 shows that only 2 years of the 26 at Harrow had deficiencies of less than 4 in.; 7 years suffered droughts of more than 10 in.

The time when droughts occur as well as their intensity is important to agriculturists. A deficiency in June or early July, such as the one that occurred in 1949 throughout most of southern Ontario, causes the failure of early fruits and reduced yields of hay and grains; a deficiency later causes poor quality and reduced yield in vegetables, late fruits and tobacco. In any month drought causes the browning of pastures and the resulting problem of feed for livestock. Table 6 shows the number of occurrences of deficiencies of varying magnitudes by months at the four stations. At Harrow, Guelph and Ottawa, 26 years of records were used, but at Walkerton only 22 complete years were available.

It is noteworthy that at all stations deficiencies were experienced in five months of the year, and at Harrow and Guelph in six months. In no year was there water deficiency in May at any of the stations. However, June droughts occurred at Harrow in 11 years of the 26, and at Walkerton, Ottawa and Guelph in 3 or 4 years.

TABLE 6.—OCCURRENCE OF MONTHLY DEFICIENCIES OF VARYING MAGNITUDES DURING PERIOD 1923-1948

HARROW

| Amount of deficiency | June | July | August | September | October | November |
|---|---|---|---|---|---|---|
| (inches) | | | | | | |
| 0 | 15 | 2 | 3 | 3 | 9 | 20 |
| 0 – 2 | 8 | 4 | 5 | 12 | 17 | 6 |
| 2 – 4 | 3 | 13 | 15 | 11 | 0 | 0 |
| 4 – 6 | 0 | 7 | 3 | 0 | 0 | 0 |

GUELPH

| | | | | | | |
|---|---|---|---|---|---|---|
| 0 | 23 | 11 | 5 | 6 | 17 | 25 |
| 0 – 2 | 3 | 9 | 12 | 16 | 9 | 1 |
| 2 – 4 | 0 | 4 | 9 | 4 | 0 | 0 |
| 4 – 6 | 0 | 2 | 0 | 0 | 0 | 0 |

OTTAWA

| | | | | | | |
|---|---|---|---|---|---|---|
| 0 | 22 | 9 | 5 | 7 | 21 | 26 |
| 0 – 2 | 4 | 10 | 10 | 18 | 5 | 0 |
| 2 – 4 | 0 | 7 | 9 | 1 | 0 | 0 |
| 4 – 6 | 0 | 0 | 2 | 0 | 0 | 0 |

WALKERTON

| | Years of record | | | | | |
|---|---|---|---|---|---|---|
| | (23) | (23) | (23) | (22) | (22) | (22) |
| 0 | 19 | 8 | 4 | 6 | 15 | 22 |
| 0 – 2 | 3 | 7 | 5 | 14 | 7 | 0 |
| 2 – 4 | 1 | 7 | 13 | 2 | 0 | 0 |
| 4 – 6 | 0 | 1 | 1 | 0 | 0 | 0 |

July is the month when highest deficiencies may be expected in the Harrow and Guelph area. At Harrow, only 2 years showed no July deficiency, but 7 had deficiencies of more than 4 in. The magnitude of this deficiency is apparent when it is realized that the average potential evapotranspiration in July is only 5.5 in. Although 11 years at Guelph showed no July deficiency, 2 years had deficiencies of more than 4 in. Ottawa was the only station of the four where a July deficiency of 4 in. was not recorded although only about one-third of the July records showed no deficiency. Similarly at Walkerton, about one-third of the years had no July deficiency. In August, Ottawa and Walkerton can expect their highest deficiencies and at all four stations it seems to be the month with the least likelihood of escape from drought. In only 5 years during the

period of observation was there no deficiency in August at Guelph and Ottawa; in only 3 years at Harrow. In the majority of years, southern Ontario can expect drought in September, although deficiencies are smaller in magnitude since water needs are smaller. At Ottawa, Walkerton and Guelph there were 6 or 7 years without moisture deficiency during September; at Harrow only 3. October is usually considered a humid month in southern Ontario with precipitation adequate for the needs of the vegetation; yet all four stations recorded deficiencies during October—in 5 years at Ottawa and in 17 years at Harrow. By November the water needs are greatly reduced and at no time during the study period did droughts occur at Walkerton or Ottawa. Slight deficiencies were experienced in the Guelph and Harrow area during November.

The small chance of escaping deficiency in any year in southern Ontario lends support to the theory that crop yields in the so-called humid East are reduced every year by invisible drought to as little as 35 per cent of the potential (6). In 1949, lack of moisture was the cause of a complete failure of the strawberry crop in most of southern Ontario. The obvious means of combating deficiency is by irrigation, and in this respect the Thornthwaite method provides a most worth-while tool. Irrigators can use the formula to determine the daily water loss from a crop, and thus the daily changes in soil moisture (as illustrated in Figure 7 for Harrow). Before the moisture reserves reach a dangerously low level, additional water to a known depth can be supplied. By following this system two

TABLE 7.—WATER SURPLUSES (IN INCHES), 1923-1948

| | Harrow | Guelph | Ottawa | Walkerton |
|---|---|---|---|---|
| 1923 | 9.46 | 12.42 | 14.22 | — |
| 1924 | 7.93 | 11.71 | 13.72 | — |
| 1925 | 6.47 | 12.89 | 16.94 | 18.26 |
| 1926 | 17.35 | 20.90 | 14.23 | — |
| 1927 | — | 16.24 | 18.11 | 16.55 |
| 1928 | 3.11 | 11.48 | 17.71 | 30.65 |
| 1929 | 8.74 | 17.96 | 15.46 | 25.50 |
| 1930 | 3.80 | 7.75 | 6.61 | 10.35 |
| 1931 | 1.39 | 9.32 | 7.63 | 11.18 |
| 1932 | 0.97 | 14.13 | 14.91 | 26.15 |
| 1933 | 3.35 | 11.06 | 16.16 | 17.71 |
| 1934 | 5.51 | 11.44 | 14.85 | 14.93 |
| 1935 | 6.82 | 8.49 | 9.93 | 12.38 |
| 1936 | 8.50 | 12.79 | 18.16 | 21.38 |
| 1937 | 14.42 | 14.30 | 15.56 | 18.39 |
| 1938 | 12.84 | 10.93 | 10.85 | 12.02 |
| 1939 | 12.06 | 11.44 | 16.36 | 16.85 |
| 1940 | 5.58 | 16.84 | 14.50 | — |
| 1941 | 4.29 | 8.20 | 13.17 | 15.59 |
| 1942 | 9.17 | 20.80 | 14.83 | 20.19 |
| 1943 | 10.24 | 11.09 | 19.94 | 16.61 |
| 1944 | 5.91 | 9.95 | 10.89 | 9.67 |
| 1945 | 8.99 | 19.78 | 17.78 | 16.43 |
| 1946 | 3.90 | 5.46 | 17.87 | — |
| 1047 | 10.53 | 13.06 | 19.26 | — |
| 1948 | 10.37 | 10.08 | 13.39 | — |
| | | | | 1921—12.85 |
| | | | | 1922—14.37 |

TABLE 8.—NUMBER OF YEARS WITH SURPLUSES OF VARYING AMOUNTS

| Surplus | Harrow | Guelph | Ottawa | Walkerton |
|---|---|---|---|---|
| (inches) | | | | |
| 0 – 4.9 | 7 | 0 | 0 | 0 |
| 5 – 9.9 | 11 | 6 | 3 | 1 |
| 10 – 14.9 | 6 | 14 | 11 | 7 |
| 15 – 19.9 | 1 | 4 | 12 | 8 |
| 20 – 24.9 | 0 | 2 | 0 | 2 |
| 25 – 29.9 | 0 | 0 | 0 | 2 |
| 30 – 34.9 | 0 | 0 | 0 | 1 |
| Number of years' record | 25 | 26 | 26 | 21 |

faults common among irrigators can be corrected—that of waiting until the plants show signs of deficiency before irrigating and that of applying too little or too much water. An irrigation system using the Thornthwaite method and applying water when the soil moisture reserves were depleted 1 in. has been used on red pine seedlings during the 1948 and 1949 seasons at the Provincial Forestry Station at Orono with substantial and gratifying increase in growth. Such a system could be applied equally well to agricultural crops such as corn, spinach or pasture grasses.

*Variations in Moisture Surplus*

During the cooler half-year in southern Ontario, precipitation greatly exceeds water need, and after the soil moisture has been recharged, a moisture surplus occurs. The geographic distribution of average annual surplus was shown in Figure 2. Much of the surplus water in southern Ontario occurs as snow and does not run off or percolate to the ground water table until spring. Surpluses are shown by calendar years at the four selected stations in Table 7. Table 8 shows the frequency of occurrence of surpluses of varying amounts.

There are as wide variations in water surplus throughout the 26-year period as there were in moisture deficiency. At Harrow the surplus may be as little as 1.0 in. (1932) or as great as 17.4 in. (1926)—a variation of more than 16 in. In 7 of the 26 years of record at Harrow the moisture surplus amounted to less than 5 in. and in only one year was it more than 15 in. These surpluses are considerably lower than for the other three stations. At Guelph, the variation in surplus was from 5.5 in. in 1946 to 20.9 in 1926—a range of 15 in. A surplus of less than 5 in. never occurred here, and 6 years recorded surpluses of more than 15 in. Ottawa had the smallest variation in moisture surplus of the four stations—from 6.6 in. in 1930 to 19.3 in. in 1947. Twenty-three of the 26 years of record had surpluses between 10 to 20 in. Although both average precipitation and average surplus are highest in Walkerton, the variation in surplus is also greatest—from 9.7 in. in 1944 to 30.6 in. in 1928. In Walkerton, as in Ottawa, the most frequent occurrences were in the 10 to 20 in. classes, but unlike Ottawa, 5 years recorded surpluses of more than 20 in.

While the chief importance of water surplus in agriculture lies in the leaching and intractability of the soil, a knowledge of the magnitude of the water surplus and its variation from year to year is most important in

understanding the hydrological cycle. The present 26-year study illustrates the variability of run-off that can be expected at four stations representative of the four major moisture regions in southern Ontario. In addition, the method used here to obtain yearly figures of water surplus from the meteorological statistics could be useful to hydrologists in estimating run-off and its variation in areas where no run-off measurements are made or where only short records are available. Worth-while correlations could also be made with changes in ground water levels.

*Variability of Moisture Index and Climatic Type*

Thornthwaite's moisture index was devised to express the relationship between surplus and deficiency and water need; and the geographic distribution of indices and resulting moisture provinces were seen in Figure 5. A humid B climatic region, however, may have a perhumid A climate in one year and a subhumid $C_2$ climate in another; similarly, a subhumid C area may be semi-arid one year and humid another. The yearly moisture indices for the four stations with the corresponding Thornthwaite climatic types are seen in Table 9, while Table 10 shows the number of occurrences of each climatic type during the 26-year period. Six climatic types occurred at Harrow and Walkerton, and five at Guelph and Ottawa.

Harrow belongs to the $C_2$ climatic type; yet of the 25 complete years of record only 9 had typical $C_2$ moisture conditions. Drier $C_1$ conditions were characteristic of 5 years and a semi-arid D climate typified 1931, 1932 and 1933. Moister-than-average $B_1$ conditions were typical of 6 years but $B_2$ and $B_3$ climates occurred in only 2 of the 25 years.

TABLE 9.—MOISTURE INDICES AND CLIMATIC TYPES, 1923-1948

| | Harrow | Guelph | Ottawa | Walkerton |
|---|---|---|---|---|
| 1923 | 18.7 $C_2$ | 47.0 $B_2$ | 44.8 $B_2$ | (1921) 42.2 $B_2$ |
| 1924 | 18.4 $C_2$ | 45.1 $B_2$ | 49.2 $B_2$ | (1922) 60.0 $B_3$ |
| 1925 | 7.4 $C_2$ | 46.3 $B_2$ | 57.3 $B_2$ | 67.2 $B_3$ |
| 1926 | 61.0 $B_3$ | 99.0 $B_4$ | 60.2 $B_3$ | — |
| 1927 | — | 65.2 $B_3$ | 70.6 $B_3$ | 61.2 $B_3$ |
| 1928 | −10.8 $C_1$ | 50.4 $B_2$ | 74.6 $B_3$ | 129.0 A |
| 1929 | 16.8 $C_2$ | 64.5 $B_3$ | 60.4 $B_3$ | 95.0 $B_4$ |
| 1930 | −18.3 $C_1$ | 14.9 $C_2$ | 19.1 $C_2$ | 26.9 $B_1$ |
| 1931 | −22.4 D | 27.0 $B_1$ | 8.2 $C_2$ | 34.0 $B_1$ |
| 1932 | −21.4 D | 59.0 $B_2$ | 53.9 $B_2$ | 108.5 A |
| 1933 | −21.8 D | 24.2 $B_1$ | 53.0 $B_2$ | 48.5 $B_2$ |
| 1934 | − 9.0 $C_1$ | 31.9 $B_1$ | 49.6 $B_2$ | 36.0 $B_1$ |
| 1935 | 13.9 $C_2$ | 23.7 $B_1$ | 35.1 $B_1$ | 42.1 $B_2$ |
| 1936 | 10.1 $C_2$ | 33.3 $B_1$ | 71.4 $B_3$ | 75.5 $B_3$ |
| 1937 | 51.6 $B_2$ | 57.8 $B_2$ | 57.0 $B_2$ | 64.0 $B_3$ |
| 1938 | 33.1 $B_1$ | 34.5 $B_1$ | 40.5 $B_2$ | 34.9 $B_1$ |
| 1939 | 27.1 $B_1$ | 23.7 $B_1$ | 68.0 $B_3$ | 67.5 $B_3$ |
| 1940 | 21.1 $B_1$ | 76.0 $B_3$ | 47.2 $B_2$ | — |
| 1941 | 1.4 $C_2$ | 18.0 $C_2$ | 32.3 $B_1$ | 40.6 $B_2$ |
| 1942 | 20.5 $B_1$ | 78.8 $B_3$ | 44.6 $B_2$ | 68.6 $B_3$ |
| 1943 | 22.2 $B_1$ | 40.5 $B_2$ | 88.5 $B_4$ | 67.5 $B_3$ |
| 1944 | − 8.5 $C_1$ | 33.6 $B_1$ | 18.5 $C_2$ | 18.8 $C_2$ |
| 1945 | 18.4 $C_2$ | 73.9 $B_3$ | 68.8 $B_3$ | 59.5 $B_2$ |
| 1946 | −13.5 $C_1$ | 12.1 $C_2$ | 69.8 $B_3$ | — |
| 1947 | 21.9 $B_1$ | 38.8 $B_1$ | 72.7 $B_3$ | — |
| 1948 | 16.9 $C_2$ | 26.2 $B_1$ | 39.1 $B_1$ | — |

TABLE 10.—OCCURRENCE OF THORNTHWAITE CLIMATIC TYPES, 1923-1948

| Climatic type | Harrow | Guelph | Ottawa | Walkerton |
|---|---|---|---|---|
| Perhumid A | 0 | 0 | 0 | 2 |
| Humid $B_4$ | 0 | 1 | 1 | 1 |
| Humid $B_3$ | 1 | 5 | 9 | 8 |
| Humid $B_2$ | 1 | 7 | 10 | 5 |
| Humid $B_1$ | 6 | 10 | 3 | 4 |
| Moist subhumid $C_2$ | 9 | 3 | 3 | 1 |
| Dry subhumid $C_1$ | 5 | 0 | 0 | 0 |
| Semi-arid D | 3 | 0 | 0 | 0 |
| Arid E | 0 | 0 | 0 | 0 |
| Number of years' record | 25 | 26 | 26 | 21 |

Guelph is typically a $B_1$ climate and 10 years of the 26 had $B_1$ moisture conditions. A drier $C_2$ climate was typical of only 3 years while moister $B_2$ and $B_3$ conditions occurred in 12 years. The year 1926 had an exceptionally moist $B_4$ climate.

Ottawa, chosen to represent the $B_2$ climatic type, had a typical $B_2$ climate in 10 years of the 26. Three years had drier $B_1$ conditions and 3 years subhumid $C_2$ conditions. In 10 years moister-than-average climatic conditions prevailed; 9 were typically $B_3$ while one (1943) had a $B_4$ climate.

Walkerton belongs to the $B_3$ climatic type, and of the 21 complete years of record here, 8 had typical $B_3$ moisture conditions. Nine years were characterized by less humid $B_1$ and $B_2$ conditions and one (1944) by subhumid $C_2$ conditions. A moister-than-average $B_4$ climate was typical of 1929 and a perhumid A climate of 1928 and 1932. Walkerton was the only station where a perhumid A climate occurred during the years under observation and Harrow the only station where semi-arid D climates were experienced.

## SUMMARY

The present study with the aid of maps and tables has presented the normals and the yearly variations in the moisture relationships in southern Ontario's climate. The geographic distributions of average water need, deficiency, surplus and actual water loss as computed by the Thornthwaite method were shown and the province divided into five major moisture regions. The greater part of southern Ontario belongs to the humid climatic province, but to the less humid $B_1$ and $B_2$ rather than the more humid $B_3$ and $B_4$ types. A considerable area in the southwest of the province is climatically subhumid.

Four stations—Harrow, Guelph, Ottawa and Walkerton—were chosen to represent the four main moisture provinces, and their daily changes in soil moisture computed for the years 1923 to 1948. Variations in precipitation and water need during the period were shown, and the subsequent variations in water deficiency and water surplus. Deficiency was treated in detail since it is the climatic factor most important in reducing crop yields in the province. At each station only one or two years during the

26-year period had no deficiency, while at Harrow deficiencies ranged as high as 16 in. per year. The frequency of occurrence of annual deficiencies of varying intensities was analysed at the four stations. In addition, the chances of deficiency during every month of the growing season were studied to indicate the times of greatest and least drought frequency.

The daily changes in soil moisture during 1948 at Harrow were plotted graphically to illustrate how the Thornthwaite method can be used in working out an irrigation system to supply supplementary water to a crop before it suffers from deficiency and yield is reduced.

Yearly variations in moisture surplus at the four stations were similarly presented, and when analysed by the hydrologists could help to explain seasonal variability in run-off and changes in ground water levels.

Finally the Thornthwaite moisture indices, relating water deficiency and surplus to need in each year were computed to indicate the number of years when average, wetter-than-average, and drier-than-average moisture conditions could be expected in the four localities.

Since three of the four stations studied are government experiment stations, it is hoped that the detailed moisture data provided here will be used in correlating climate with the growth, yield and quality of crops and with the occurrence of plant diseases and insect infestations.

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# RECENT FIELD TESTS ON THE EFFECT OF SOIL FUMIGANTS UPON BROWN ROOTROT OF TOBACCO IN ONTARIO

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The testing of soil fumigants, for the control of brown rootrot of tobacco has recently been reported from most of the more northern tobacco-growing states of the United States. In Connecticut, Anderson (1) and, in North Carolina, Nusbaum and Todd (3) report the successful use of ethylene dibromide and a mixture of dichloropropylene and dichloropropane. In Kentucky, Valleau (4) reports non-beneficial results with one fumigant. Kincaid (4) reports that soil fumigation does not control meadow nematodes as well as it does root knot nematodes. The effect on quality has been variously reported by different workers.

## EXPERIMENTAL

For several years past the effect of various soil fumigants upon the growth of burley tobacco in typical "brown rootrot" soil has been investigated at Harrow, Ontario. Exploratory tests conducted for two years prior to 1949 showed consistent but variable increase (up to 300 per cent) in growth of tobacco on brown rootrot soil to which either dichloropropylene-dichloropropane mixture or ethylene dibromide was applied broadcast at either 20 or 30 gal. per acre.

During the current year it became possible to conduct soil fumigation tests under highly favourable conditions. A plot (235′ × 150′) of Fox sandy loam soil carefully selected because of its record for occurrence of brown rootrot was used for the experiment. A heavy crop of corn which in Ontario has always proved to be the crop most conducive to severe brown rootrot in the subequent tobacco crop, was produced on this plot in 1948 and the entire growth, including stalks, was ploughed under in the spring of 1949. Six chemicals were used, namely, methyl bromide (xylene base), methyl bromide (carbon tetrachloride base), chloropicrin, ethylene dibromide, and dichloropropylene-dichloropropane mixture. All chemicals were applied with a common type (Mack) hand injector in the tobacco row 10 days prior to planting, the injections being made at a depth of 4–5 inches at 8-inch intervals along rows 40 inches apart. The soil had been ploughed, disked, and cultipacked previous to treatment and was moderately moist at the time of application of the chemicals. No seal was used. No rainfall occurred between May 30, the date of application, and June 9, when the tobacco was planted by machine. The plot was divided into four separate ranges and single alternate rows of the varieties Harrow Velvet and Green Briar were planted in each range. Harrow Velvet is completely susceptible to brown rootrot (2) while Green Briar is the most resistant of the burley varieties commonly grown in Ontario. In most cases there were five randomized replicates of each treatment. A single test unit comprised 18 plants. Treatments are listed in Table 1 and results are summarized in Tables 2 and 3.

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TABLE 1.—LIST OF FUMIGANTS APPLIED TO FIELD SOIL INFESTED WITH BROWN ROOTROT OF TOBACCO AND AMOUNTS USED

| Treatment designation | Fumigant | Amount (cc.) per 8-inch centre |
|---|---|---|
| $MB_1$ | Methyl bromide (15%) (xylene base) | 6* |
| $MB_2$ | Methyl bromide (15%) (xylene base) | 10 |
| $MB_3$ | Methyl bromide (10%) (Carbon tetrachloride base) | 10 |
| Dowfume G | | |
| Dow W40 | Ethylene dibromide | 6 |
| Cp | Chloropicrin | 6 |
| Dow N | Dichloropropylene-dichloropropane | 6 |
| $P_1$ | Parathion | 6 |
| $P_2$ | Parathion | 10 |

* 6 cc. per 8-inch centre equivalent to 30 gal. per acre.

TABLE 2.—RELATIVE ROOT INJURY ON BURLEY TOBACCO IN BROWN ROOTROT FIELD PLOTS TO WHICH DIFFERENT SOIL FUMIGANTS WERE APPLIED BY ROW INJECTION METHOD*

| Treatment | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| MB** | $P_1$ | $P_2$ | $MB_1$ | $MB_2$ | Dow W40 | Dow N | Cp | Checks | |
| | | | | | | | | Green Briar | Harrow Velvet |
| Percentage root injury | | | | | | | | | |
| 20 | 100 | 55 | 75 | 10 | 40 | 5 | 5 | 20 | 70 |
| 100 | 30 | 90 | 10 | 40 | 5 | 5 | 5 | 15 | 100 |
| 80 | 95 | 100 | 5 | | 15 | 10 | 5 | 20 | 90 |
| | 60 | 40 | 40 | | 10 | 10 | 5 | 50 | 100 |
| | 40 | 30 | 30 | | 30 | 15 | | 50 | 100 |
| Average root injury | | | | | | | | | |
| 66 | 65 | 63 | 32 | 25 | 20 | 9 | 5 | 31 | 92 |

F = 11, L.S.D. at 5% = 2.7.

* Based on macroscopic examination of roots of 6 random plant samples from each of 5 replications. Higher figures represent greater root injury.

** For key to treatments, see Table 1.

An examination of averages in Table 2 indicates marked differences in root injury among plots of the susceptible variety Harrow Velvet treated with the various soil fumigants. Average root injury was less on all fumigated than on non-fumigated plots of the susceptible variety, regardless of the chemical used. As will be noted, root injury varied from as little as 5 and 9 per cent in the chloropicrin- and Dow N-treated plots, respectively, up to 65 and 66 per cent in the plots treated with Parathion and $MB_3$, respectively. In non-treated soil, root injury averaged 31 per cent in the resistant Green Briar variety and 92 per cent in the susceptible Harrow Velvet. Thus, the average root injury on the resistant variety in non-treated but infested soil occupied a position approximately midway between the greatest and the least average injury among the fumigated plots of the susceptible variety.

TABLE 3.—GREEN WEIGHT YIELDS OF BURLEY TOBACCO IN BROWN ROOTROT FIELD PLOTS TO WHICH DIFFERENT SOIL FUMIGANTS WERE APPLIED BY ROW INJECTION METHOD*

| Treatment | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Dow N | Chloro-picrin | Dow W40 | $MB_1$ | $MB_2$ | $P_1$ | $MB_3$ | $P_2$ | Checks | |
| | | | | | | | | Green Briar | Harrow Velvet |
| | | | | | lb. | | | | |
| 16 | 20 | 12 | 3 | 3 | 1 | 7 | 2 | 20 plots | 14 plots |
| 23 | 23 | 13 | 15 | 6 | 4 | 2 | 1 | | |
| 22 | 7 | 7 | 13 | | 1 | 1 | 2 | | |
| 11 | 13 | 20 | 16 | | 8 | | 4 | | |
| 20 | | 18 | 12 | | 7 | | 4 | | |
| | | | | | Total weight (lb.) | | | | |
| 92 | 63 | 70 | 59 | 9 | 21 | 10 | 13 | 360 | 280 |
| | | | | | Av. lb. per plot | | | | |
| 18.4 | 15.6 | 14.0 | 11.8 | 4.5 | 4.2 | 3.3 | 2.6 | 18.0 | 2.0 |

F = 9.4, L.S.D. at 5% = 2.7.
* Six plants were weighed in each plot at "topping" stage.

From Table 3, it is evident that a wide range of green-weight yields prevailed among the fumigated plots of the susceptible variety. These range from 2.6 lb. in the Parathion-treated plots to 18.4 lb. in the Dow N-treated plots. Among the non-treated plots, yields averaged 18.0 lb. in the Green Briar plots (Figure 1, B; Figure 2, B; and Figure 3, A, C, and E) and only 2 lb. in the Harrow Velvet plots (Figure 1, C; Figure 2, C; and Figure 3, B and D). Thus, as far as the susceptible variety is concerned, the least growth of all occurred on the non-treated plots. On the other hand, the green weight yield of the susceptible variety in plots treated with Dow N (Figure 2, A) was slightly greater than that of the resistant variety in non-treated soil. Thus, the application of Dow N to brown rootrot soil resulted in an increase of 920 per cent for the susceptible variety.

Table 4 shows that, in treated rows of Green Briar yields of 11 and 18 lb. in the Dow N and Dow W40 plots, respectively, were obtained. These yields, it will be noted, are no higher than those in untreated rows of the same variety (see Table 3). On the other hand, the yield of Harrow Velvet—1 and 13 lb. in the Dow N and Dow W40 plots, respectively, in fumigated soil—represents an increase of 11 to 13 times that of adjacent checks of the same variety.

Statistical analyses of results in Tables 2 and 3, except for $MB_2$ and $MB_3$, where an insufficient number of plants were available for inclusion, showed significant differences both in root injury and in green weights between all fumigation treatments. A correlation was also indicated between root injury and green weights though the coefficient of correlation (−.41) was not so high as might be expected, probably because only a single set of root observations could be made.

It should also be mentioned that from the time late in June, when plot differences first became apparent, brown rootrot was obviously severe on Harrow Velvet throughout the entire field experiment where soil fumigants

FIGURE 1. Brown rootrot soil fumigation plots. A—Harrow Velvet (chloropicrin-treated). Some plants had been harvested from this row before photograph was taken. B—Green Briar (no treatment). C—Harrow Velvet (no treatment). Note severe stunting.

FIGURE 2. Brown rootrot soil fumigation plots. A—Harrow Velvet (Dow N-treated). Some plants had been harvested from this row before photograph was taken. B—Green Briar (no treatment). C—Harrow Velvet (no treatment). Note severe stunting.

FIGURE 3. Brown rootrot soil fumigation plots. A—Green Briar (no treatment). B—Harrow Velvet (no treatment). C—Green Briar (no treatment). D—Harrow Velvet (no treatment). E—Green Briar (no treatment). N.B.—Green Briar resistant. Harrow Velvet susceptible.

TABLE 4.—GREEN WEIGHT YIELDS OF SINGLE PLOTS OF BURLEY TOBACCO IN BROWN ROOTROT FIELD SOIL WHERE FUMIGANTS WERE APPLIED BY BROADCAST METHOD*

| Treatment | Variety | | Check |
|---|---|---|---|
| | Harrow Velvet | Green Briar | Harrow Velvet |
| | | lb. | |
| Dow N | 11 | 11 | 1 |
| Dow W40 | 13 | 18 | 1 |

* 4 cc. per injection; spacing 8 × 10 inches.

were not used. Many rows of this variety remained less than 3 inches in height throughout the season. These were in marked contrast with adjacent rows of Green Briar which ranged from 2 to 3 feet in height.

*Microscopic Examination of Roots*

Periodic microscopic examinations of roots of plants from non-treated plots were made during the summer. These revealed discolored root areas—the brown to black individual cells lacking any evidence of the presence of bacteria or fungi—and nematodes in various stages of development, all of which are so characteristic of the condition regarded as typical brown rootrot in Ontario. Immersion of affected roots in water overnight revealed the presence of a fair abundance of nematodes of different species. However, there was no correlation between the number of nematodes found and the severity of root injury.

Specimens of diseased roots submitted to G. Steiner confirmed the presence of meadow nematodes in them. Dr. Steiner states "the form involved is very close to one that is called the broad-headed nematode. It is not the type found in, for example, Florence, South Carolina, but it is present in Chatham, Virginia and Connecticut. In the material submitted they were not very numerous. We also found in these plants *Tylenchorlynchus claytoni*. This is a form that is continuously observed on dwarfed plants. We suspect this species to be very poisonous to the plant host. In Connecticut also this species is associated with plants of dwarfed appearance. In your instance, the invasion obviously was a very early one. Other parasitic nematodes found in these roots belong to the stem nematode, *Ditylenchus* sp."

## SUMMARY

1. Six soil fumigants were applied to tobacco brown rootrot field soil and their relative effects on burley tobacco were compared.

2. Chemicals were applied in the row at different rates with a hand injector 10 days before planting.

3. Extremely wide differences in root injury and green weight yields were obtained between treated and non-treated plots of the susceptible variety Harrow Velvet.

4. The soil fumigants apparently acted as nematicides in the present experiments.

5. It is indicated that the variety Green Briar is much more tolerant to nematode populations in brown rootrot soil than most other varieties grown in Ontario.

6. Of the various fumigants used, Dow N, Chloropicrin, and Dow W40 resulted in greatly increased growth of the susceptible variety Harrow Velvet and thus appear to offer particular promise for the control of brown rootrot of tobacco.

## ACKNOWLEDGMENT

Acknowledgment is due W. E. McKeen of the Harrow staff for the statistical analyses, and to the Dow Chemical Company, Midland, Michigan, for providing all chemicals used, except Chloropicrin and Parathion.

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# ARASAN AS A SEED AND SOIL TREATMENT FOR THE CONTROL OF DAMPING-OFF IN CERTAIN VEGETABLES

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## INTRODUCTION

In southwestern Ontario, as in many other extensive vegetable-growing areas, damping-off of seedlings grown in flats or beds under greenhouse conditions is one of the most destructive diseases, and, until recently, many growers have accepted as unavoidable heavy losses in stands of young plants due to this trouble. In general, damping-off has been most severe where soil sterilization has not been practised. Nevertheless, in many large commercial houses, even when treated seed has been planted in steamed soil, appreciable losses have been sustained, particularly in stands of peppers, eggplant and Spanish onions. Moreover, when spot infections develop in flats of seedlings grown in steamed soil, the spread of the disease is usually more rapid, and the final loss is often greater than where non-steamed soil is used.

The annual losses suffered by growers, particularly those possessing no facilities for steaming seedbed soils, has warranted a search for improved control measures.

## RECENT DEVELOPMENTS IN CONTROL OF DAMPING-OFF

In recent years, the wide adoption of seed treatment by most vegetable growers has closely followed the development of suitable seed protectants in dust form, several of which have shown a marked capacity to reduce pre-emergence damping-off. Especially noteworthy in this connection are the findings of Taylor and Rupert (7), who showed, in 1946, that seed treatment of spinach with Arasan is distinctly superior to treatment with Spergon and cuprous oxide in reducing post-emergence damping-off because of the more prolonged protective action of the first-mentioned material. More recently, a different approach to the control of certain soil-borne pathogens was developed at the Harrow laboratory by Hildebrand (4) and Hildebrand and co-workers (5), who showed that formulations of thiram (50 per cent non-wettable) when applied to the soil in the vicinity of sugar-beet seeds, effectively controlled both the pre-emergence and post-emergence phases of blackroot, a damping-off type of disease. Doran (1, 2), by a somewhat similar approach, has recently shown that damping-off of certain vegetables has been more effectively controlled by mixing certain organic fungicides with commercial fertilizers and applying them to the soil before seeding rather than in water after seeding.

Inasmuch as seed treatment with Arasan and several other of the newer fungicides failed to protect pepper seedlings adequately against post-emergence damping-off, the writer during the past three years has com-

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pared the effectiveness of seed and soil treatments with several fungicides for control of the disease in peppers and in certain other vegetables caused by *Pythium* spp. and *Rhizoctonia Solani* Kühn. In 1948 some preliminary results were reported (6). Further experiments and results are presented in this paper.

## MATERIALS AND METHODS

The experiments were carried out in standard wooden flats 24″ × 12″ × 4″, under ordinary greenhouse conditions. Air temperatures varied from 60°–90° F. and, for the most part, closely approximated those obtaining in commercial greenhouses. In all experiments, the flats were sprinkled once or twice daily to maintain a moderately high soil moisture.

A compost mixture, designated type A, comprising Fox sandy loam soil, muck and well-rotted manure, was used in the first experiments reported in this paper. In later experiments another compost, type B, containing only Fox sandy loam soil and muck, was used. In the first-mentioned soil, damping-off organisms were abundant; but in the second it was necessary to add both *Pythium ultimum* and *Rhizoctonia Solani*, which were cultured on a cornmeal-sand medium. The inoculum was added to the soil 24–72 hours prior to seeding.

In preliminary trials, several of the newer fungicides were tested for control of damping-off in peppers. Of these, Arasan (50 per cent tetramethyl thiuram disulphide, non-wettable) gave consistently the best results and for this reason most of the experiments described below centred around the use of this chemical.

To ensure as uniform germination as possible in each test, small, light and off-type seeds were discarded. In spinach, the large seeds were not planted.

Seed treatment of these vegetables was carried out according to methods generally employed and precautions were taken to obtain uniformity in all tests. The dosage rates with Arasan were as follows: pepper—0.38 per cent, spinach—0.40 per cent, tomatoes—0.75 per cent, and 2.5 per cent, onion—0.24 per cent, cucumber—0.40 per cent, muskmelon—0.24 per cent, lettuce—2.0 per cent, and celery—2.8 per cent.

For soil treatment, the required amount of the protectant was uniformly mixed with the soil in the flat previous to planting. With the exception of preliminary tests with peppers, Arasan was applied to the soil at the rate of 3.14 gm. per cu. ft.

Uniformity of planting was obtained by seeding in depressed rows always of a fixed depth, 3/16 inches for small seeds, such as those of celery and lettuce, and 7/8 inches for large seeds, such as those of cucumber and muskmelons. After the seeds were evenly spaced in the row, the depression was filled, the seeds thereby being covered.

Counts of seedlings were made daily and those that damped-off were recorded and removed. The analysis of variance, as given by Hayes and Immer (3), was employed to determine significant differences between surviving stands of seedlings.

## EXPERIMENTAL RESULTS

### Arasan as a Protectant for Peppers

*(a) Preliminary Tests*

With the use of soil type A, preliminary tests had shown that 3.14 gm. of Arasan per cu. ft. of soil appeared to be effective in controlling the disease without being injurious to the host. Subsequently, the chemical was tested at double and triple this concentration. All soil treatments were checked against seed treatment alone and against a combined seed and soil treatment, five flats comprising the test unit in the various experiments. The results are summarized in Table 1.

As Table 1 indicates, all treatments resulted in considerably greater emergence than the check. Emergence was highest where Arasan was applied to the soil at the rates of 6.28 and 9.42 gm. per cu. ft. At these concentrations, however, subsequent growth of pepper seedlings was much retarded. No delay in emergence or retardation of later growth was apparent in the other treatments. The highest incidence of post-emergence damping-off, namely, 43.2 per cent occurred in the non-treated control. When seed alone was treated, the incidence of post-emergence damping-off was 35.2 per cent, indicating the relative ineffectiveness of seed treatment in controlling this phase of the disease. Soil treatment at the rate of 3.14 gm. allowed 14.6 per cent post-emergence damping-off and, when seed treatment was combined with soil treatment at the above-mentioned rate, post-emergence damping-off was reduced to 8.6 per cent, and the best stand of pepper seedlings was obtained.

TABLE 1.—EFFECT OF TREATMENT OF SEED, OF SOIL, AND OF SEED AND SOIL WITH ARASAN ON EMERGENCE AND DAMPING-OFF IN PEPPER SEEDLINGS

| Arasan treatment | | Toxicity effects | 22 days after planting | | |
|---|---|---|---|---|---|
| | | | Emergence* % | Post-emergence** damping-off % | Stand* % |
| Seed | (0.38%)† | None | 87.1 | 35.2 | 56.6 |
| Seed and Soil | (0.38% and 3.14 gm.)‡ | None | 93.0 | 8.6 | 84.7 |
| Soil | (3.14 gm.) | None | 87.0 | 14.6 | 74.6 |
| " | (6.28 gm.) | Appreciable stunting | 96.4 | 8.7 | 88.0 |
| " | (9.42 gm.) | Marked stunting | 96.6 | 2.1 | 94.6 |
| None | | None | 76.8 | 43.2 | 43.6 |
| Diff. for significance at 5% | | | | | 9.7 |

* Throughout this study emergence and stand are expressed as percentages of the number of seedlings emerged and surviving, respectively, in relation to the number of seeds planted.
** Post-emergence damping-off is expressed as a percentage of affected seedlings in relation to emergence.
† By weight of seed.
‡ Per cu. ft. of soil.

The daily progress of seedling emergence and damping-off resulting from seed treatment, combined seed and soil treatment, and no treatment is shown graphically in Figure 1. This chart reveals the effectiveness of soil treatment in controlling post-emergence damping-off. The ineffectiveness of seed treatment alone in controlling this phase of the disease is shown by the similarity in slope of the curves for this treatment and the control.

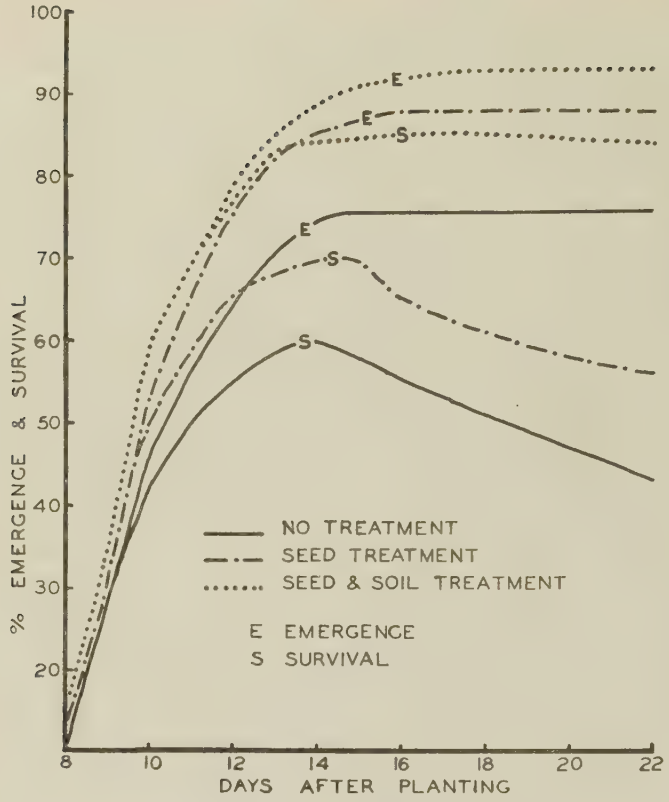


FIGURE 1. Emergence and survival of pepper seedlings as functions of time and treatment.

*(b) Confirmatory tests*

Following the preliminary trials described above, two additional similar experiments were conducted, one in the autumn and one in the spring. As the supply of naturally-infested compost soil type A was exhausted, type B was used in these experiments. The proportion of *Pythium* to *Rhizoctonia* in the inoculum added to this soil was in the ratio of 2 : 1, respectively. The results of the two tests being essentially similar, they were averaged and are presented in Table 2.

As Table 2 indicates, all treatments gave significantly better stands than the check. The combined seed and soil treatment proved to be superior to either seed or soil treatment alone and thus confirmed the results obtained in preliminary trials. In these tests, however, seed treatment was more effective in controlling the post-emergence phase of the disease than in the previous experiments. The reason for this difference is not evident. It should be mentioned, however, that, as a result of adding *P. ultimum* and *R. Solani* to the soil in the last two tests, the ratios of the damping-off pathogens would be somewhat different from those obtaining in non-inoculated soils. A photographic comparison between check and the combined seed and soil treatment is presented in Figure 2.

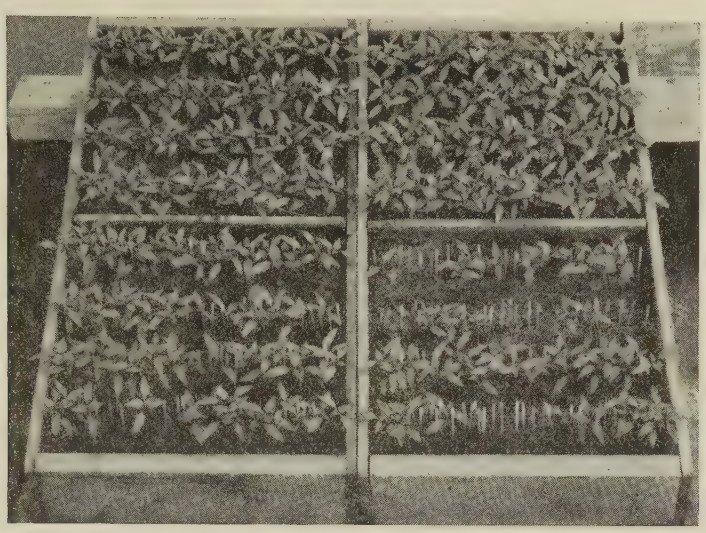

FIGURE 2. Effectiveness of Arasan seed and soil treatment in controlling damping-off in peppers. Treated seed planted in treated soil in upper half of both flats. No treatment in lower half of flats. Photograph taken 24 days after seeding.

## Arasan as a Protectant for Other Vegetables

The highly satisfactory results obtained with peppers prompted similar tests with spinach, Spanish onions, lettuce, celery, cucumbers, muskmelons and tomatoes. Soil type B was used in these tests. The details and results of these experiments are summarized in Table 3.

With respect to cucumbers and muskmelons, Table 3 shows that all treatments produced highly significant increases in stand over the non-treated controls. No significant differences were evident between the seed or soil treatments with cucumbers. In muskmelons, however, the best stand of seedlings was obtained from the Arasan seed treatment alone. Post-emergence damping-off in muskmelons was appreciably greater in soil-treated flats than in either check or seed-treated ones. It should be

TABLE 2.—EFFECT OF TREATMENT OF SEED, OF SOIL AND OF BOTH SEED AND SOIL WITH ARASAN ON EMERGENCE AND DAMPING-OFF IN PEPPER SEEDLINGS

| Arasan treatment | | 24 days after planting | | |
|---|---|---|---|---|
| | | Emergence* % | Post-emergence* damping-off % | Stand* % |
| Seed | (0.40%) | 84.6 | 12.1 | 72.2 |
| Soil | (3.14 gm.) | 74.0 | 12.5 | 65.1 |
| Seed and soil | (0.14% and 3.14 gm.) | 88.5 | 5.9 | 84.2 |
| None | | 65.8 | 29.1 | 48.2 |
| Diff. required for significance at 5% level | | | | 9.5 |

* Average of 2 experiments, both containing 5 replications of 100 seeds each.

TABLE 3.—EFFECT OF TREATMENT OF SEED, OF SOIL, OF SEED AND SOIL WITH ARASAN ON EMERGENCE AND DAMPING-OFF IN CUCUMBERS, MUSKMELONS, SPANISH ONIONS, SPINACH AND TOMATOES

| Host | Arasan treatment | Emergence* % | Post-emergence* damping-off % | Stand* % | Toxicity effects |
|---|---|---|---|---|---|
| | | | *22 days after planting* | | |
| CUCUMBERS | Seed (0.40%) | 92.0 | 0.0 | 92.0 | Nil |
| | Soil** | 92.4 | 2.6 | 90.0 | Nil |
| | Seed and soil | 96.4 | 2.0 | 94.4 | Nil |
| | None | 12.0 | 13.3 | 10.4 | Nil |
| | Diff. for significance at 5% | | | 5.27 | |
| | | | *23 days after planting* | | |
| MUSKMELONS | Seed (0.24%) | 88.8 | 1.4 | 87.6 | Nil |
| | Soil | 79.6 | 15.1 | 68.0 | Slight stunting |
| | Seed and soil | 90.4 | 12.0 | 79.6 | Slight stunting |
| | None | 41.2 | 7.7 | 38.0 | Nil |
| | Diff. for significance at 5% | | | 11.51 | |
| | | | *29 days after planting* | | |
| SPANISH ONIONS | Seed (0.24%) | 30.2 | 42.1 | 17.5 | Nil |
| | Soil | 75.5 | 15.2 | 66.5 | Nil |
| | Seed and soil | 82.5 | 10.0 | 74.2 | Nil |
| | None | 20.5 | 54.8 | 9.2 | Nil |
| | Diff. for significance at 5% | | | 6.70 | |
| | | | *23 days after planting* | | |
| SPINACH*** | Seed (0.40%) | 22.4 | 23.7 | 17.1 | Nil |
| | Soil | 43.3 | 9.0 | 39.1 | Slight stunting |
| | Seed and soil | 50.4 | 10.5 | 45.1 | Slight stunting |
| | None | 17.2 | 27.1 | 11.4 | Nil |
| | Diff. for significance at 5% | | | 5.63 | |
| | | | *28 days after planting* | | |
| TOMATOES | Seed (0.75%) | 89.4 | 2.1 | 87.5 | Nil |
| | Soil | 75.6 | 7.9 | 69.8 | Slight delay in germination |
| | Seed and soil | 85.6 | 2.2 | 83.8 | |
| | None | 65.1 | 23.4 | 49.9 | Nil |
| | Diff. for significance at 5% | | | 9.10 | |

* These results are averages of 5 replications of 100 seeds each for all treatments for onions, spinach and tomatoes, and of 50 seeds each for cucumbers and muskmelons.
** Arasan was applied at the rate of 3.14 gm. per cu. ft. of soil in all soil treatments referred to in this table.
*** The germinating capacity of the spinach seed used in these tests was approximately 58%.

mentioned that this phase of the disease did not develop in soil treatments until the seventh day after emergence. Further evidence that Arasan, when applied to the soil, was slightly injurious to young muskmelon plants and thereby seemingly rendered them more susceptible to attack, was indicated by a conspicuous retardation in early growth of seedlings.

When isolations were made from 12 muskmelon seedlings that damped-off in soil-treated flats, the cultures obtained yielded 11 of *Rhizoctonia* and one of *Pythium*, indicating that the former fungus was predominantly responsible for the disease at that stage.

If reference is made to Table 3 again, it is apparent that seed treatment afforded some small measure of protection to onion seedlings during the early stages of growth, as evidenced by an increase in emergence from the treated seed over the check. That seed treatment provided protection for only a short period of time was demonstrated by the relatively low emergence and the high incidence of post-emergence damping-off. Soil treatment alone and the combined seed and soil treatments were distinctly more effective than seed treatment in controlling both phases of the disease, as they gave much higher emergence and lower incidence of post-emergence damping-off. At the termination of the experiment, the stand of onion seedlings from soil treatment was almost four times greater than that obtained from seed treatment.

For the control of damping-off in spinach, the superiority of soil treatment over seed treatment is readily apparent. The former not only permitted much higher emergence but also controlled post-emergence damping-off more effectively than the latter. Moreover, a combined seed and soil treatment controlled the pre-emergence and post-emergence phases of the disease more effectively than soil treatment alone. Mention should be made, however, that applications of Arasan to the soil caused a slight retardation in the early growth of spinach seedlings, especially under conditions conducive to rapid growth.

For tomatoes, all treatments were significantly superior to the check. Seed treatment alone gave slightly higher emergence and final stands than the combined seed and soil treatment. Soil treatment alone was inferior to seed treatment in respect to the protection afforded against pre-emergence and post-emergence phases of damping-off. There was also observed a significant retardation in emergence of seedlings to the extent of 12–36 hours when Arasan was applied to the soil. Moreover, it was demonstrated in earlier trials that a similar delay could be obtained by applying heavy dosages to the seed.

The data concerning tests with celery and lettuce are not presented as the incidence of damping-off was too low to indicate the value of treatments. It was observed, however, that seedling emergence in these two vegetables was delayed and reduced by the Arasan treatments, thus indicating appreciable toxicity of the chemical to these crops.

### Comparative Effectiveness of Arasan and Formaldehyde Treatments in Controlling Damping-off in Tomatoes

As some growers in southern Ontario have considered the treating of soil with formaldehyde prior to planting essential to the production of uniformly good stands of tomato seedlings, a comparison between Arasan and formaldehyde treatments for disease control seemed desirable. For this experiment formaldehyde dust was applied to the soil at the rate of 215 gm. per cu. ft. The Arasan treatments were the same as those in the previous test. Four weeks after planting, all seedlings were removed from the flats. They were then washed free from soil, and the roots and hypocotyl were examined for presence of brownish lesions caused by *Rhizoctonia*. The results of the experiment are summarized in Table 4.

An examination of Table 4 reveals that all treatments were effective in controlling damping-off. It was observed that the emergence was slower in the Arasan treatments than with the formaldehyde treatment, but the

TABLE 4.—COMPARATIVE EFFECTIVENESS OF ARASAN AND FORMALDEHYDE TREATMENTS IN CONTROLLING DAMPING-OFF OF TOMATOES

| Treatment | | Percentage* of plants 28 days after planting | | | |
|---|---|---|---|---|---|
| | | Emergence | Post-emergence damping-off | Stand | Lesioned** |
| Arasan on seed | (2.5%) | 96.7 | 0.0 | 96.7 | 32.8 |
| Arasan in soil | (3.14 gm.) | 91.7 | 0.3 | 91.5 | 40.6 |
| Arasan on seed and in soil | (2.5% and 3.14 gm.) | 96.2 | 0.0 | 96.2 | 7.4 |
| Formaldehyde dust in soil | (215 gm.) | 97.5 | 0.3 | 97.2 | 9.2 |
| No treatment | | 53.5 | 2.8 | 52.0 | 65.8 |

* Average of 2 replications of 200 seeds each.
** These values represent the percentage of surviving plants exhibiting prominent *Rhizoctonia* lesions on either the lower part of the hypocotyl or upper region of the primary root.

final emergence was almost the same. The initial advantage gained from the earlier emergence in the formaldehyde-treated soil was retained and manifested in subsequent above-ground growth of the plants. In the Arasan treatments, however, the young plants were darker green in colour and were sturdier than those growing in the formaldehyde-treated soil. From an examination of seedlings for presence of lesions caused by *Rhizoctonia*, it was found that disease control was approximately the same in the combined Arasan seed and soil treatment as in the formaldehyde treatment. These two treatments were markedly more effective than either the Arasan seed or soil treatment alone.

## DISCUSSION OF RESULTS

For many years, much research has been aimed at finding a suitable seed treatment that would not only disinfect the seed surface but would also protect the seedlings during the entire period of susceptibility to damping-off pathogens. In the light of the foregoing results, it would seem that in the case of such vegetables as onions and spinach, which are highly susceptible to damping-off both before and after emergence, seed treatment with Arasan falls far short of providing the requisite protection. Furthermore, a crop very susceptible to damping-off for a long period after emergence, such as peppers, requires more than a protective seed treatment. From the results of the above-described experiments, it would appear that seed treatment with Arasan furnishes the germinating seed with immediate protection and that the soil treatment affords the seedling additional protection after it has emerged beyond the sphere of influence of the chemical. It is suggested that the efficacy of seed treatment on certain large-seeded vegetables, such as cucumbers and muskmelons, might be explained by the influence of the chemical radiating over a sufficiently large area of soil to protect the seedling for the required period. Similarly, the lack of control afforded by seed treatment on certain small-seeded vegetables, such as onions and spinach, might be due to inadequate spatial protection.

Due to the suppression of attack by *Rhizoctonia* through soil treatment with Arasan for a period of time rather than the complete elimination of the pathogen, the advisability of treating all the soil in the flat may be questioned.* Hildebrand *et al.* (5) showed that the incidence of blackroot in sugar beets was negligible if the seedlings grew up through soil treated with Arasan. Similarly, it may well be that, in vegetables, adequate protection may be obtained by treating only the soil covering the seed. Moreover, the possibility exists that toxicity to Arasan may be reduced in such hosts as muskmelons, lettuce and celery by treating only a limited amount of soil in the flat. Further experiments will be necessary to decide this issue.

Although soil treatment may have the slight disadvantage of increasing the amount of labour required at seeding time, nevertheless, the benefits to be derived from the treatment, where it may be used, would appear to more than offset the former. The treatment may be regarded as of particular benefit to vegetable growers who possess no facilities for steam sterilization of soils.

## SUMMARY

A comparative study of the effectiveness of seed treatment, of soil treatment, and of a combined seed and soil treatment with Arasan and certain other chemicals was conducted in an effort to control damping-off of peppers, tomatoes, spinach, Spanish onions, cucumbers, muskmelons, lettuce and celery.

Damping-off of spinach and Spanish onions was more effectively controlled by soil treatment with Arasan at the rate of 3.14 gm. per cu. ft. of soil than by seed treatment, but a combined seed and soil treatment with Arasan was better than soil treatment alone.

Significantly better stands of pepper seedlings were obtained from use of the combined treatment than from either one alone; soil treatment was effective in controlling the post-emergence phase of the disease for a longer time than was seed treatment.

In tomatoes, seed treatment with Arasan gave effective control of damping-off in the seedbed. The combined Arasan treatment was as effective in disease control as was the widely used formaldehyde soil treatment, but the former usually retarded emergence by a few hours.

By seed treatment, cucumbers and muskmelons were afforded a high degree of protection. In soil treated with Arasan, the incidence of post-emergence damping-off in muskmelons was higher than in the non-treated control, indicating that the chemical was injurious to this vegetable when applied to the soil.

Arasan, when applied to either the seed or the soil, was toxic to both lettuce and celery, as indicated by delayed and reduced emergence.

## ACKNOWLEDGMENTS

The author wishes to express his gratitude to L. W. Koch and A. A. Hildebrand, of the Harrow laboratory, for helpful criticism of the manuscript.

* This statement is based upon more recent experiments, the results of which will be made known in a later publication.

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# DIGESTIBILITY STUDIES WITH FOXES

## III. DIGESTIBILITY OF SOME FOX FEEDS AND FOX RATIONS[1]

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[Received for publication February 10, 1950]

Two previous papers from this Station (4, 5) have reported the digestibility coefficients of several meat products commonly fed to foxes in Canada. In another paper Inman (3) reported the digestibility coefficients of a number of commercial fox feeds. However, since this report was published, many changes have been made in these mixed feeds, both in the ingredients used and in their percentage composition. Therefore further digestibility trials on these newer rations were carried out during the winter of 1948-49.

This paper reports the chemical composition and digestibility coefficients of a number of meat by-products, vegetables, complete fox rations and also a few commercial fox feeds commonly used by Canadian fox ranchers.

### PROCEDURE

Adult male foxes (over one year of age) were used in all cases except when pup rations were fed and then approximately 10-months-old male pups were used. Each of the feeds and rations reported in this paper were fed to at least four different foxes and the average digestibility coefficient calculated.

All feeds were fed in the ground state. Beef manifolds, fox carcasses, whalemeat, and the four rations containing raw and cooked cereal were fed alone at the rate of 300 gm. per fox each day. All other feeds tested were fed in combination with horse-meat and their digestibility coefficients calculated by difference. Blood meal, ground green bone, bone meal, the two fish meals, meat meal, and the eleven commercial mixed feeds were fed at the rate of 50 gm. per day together with 150 gm. of ground horse-meat. The cabbage, carrots, turnips, and frozen fish rations were fed at the rate of 150 gm. to 150 gm. of horse-meat while the canned tomatoes were fed at the rate of 190 gm. to 150 gm. of ground horse-meat. Where necessary, sufficient water was added to the mixture to bring it to a "hamburger" consistency. These quantities were readily consumed by the foxes used on the feeding trials. Each day's ration for the entire feeding trial was weighed, wrapped in wax paper and frozen until the day it was to be fed.

Each trial was of seven-day duration. On the second day 0.5 gm. of ferric oxide was added to the ration as recommended by Bell and Crampton (2) and this marked feces was collected. On the seventh day 0.5 gm. of ferric oxide was again added to the ration and the marked feces was discarded. Thus there were five days' feces collected. The metabolism cages used in these feeding trials and the method of preserving the feces were the same as used in previous trials (4, 5).

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TABLE 1.—CHEMICAL COMPOSITION OF FOX FEEDS AND RATIONS AVAILABLE IN CANADA

| | Dry matter | Protein (N × 6.25) | Crude fat | Crude fibre |
|---|---|---|---|---|
| | % | % | % | % |
| Beef manifolds | 21.6 | 11.6 | 8.9 | — |
| Blood meal | 89.4 | 79.2 | 1.3 | — |
| Bone; ground green | 60.3 | 21.2 | 14.4 | — |
| Bone meal, steamed | 92.3 | 25.4 | 5.1 | — |
| Cabbage, fresh | 7.7 | 1.5 | 0.5 | 1.2 |
| Carrots, fresh | 12.0 | 1.2 | 0.3 | 1.1 |
| Fish, frozen (Novascot fishblox) | 23.5 | 16.1 | 1.3 | — |
| Fish meal (low fat) | 90.6 | 65.1 | 2.9 | — |
| Fish meal (high fat) | 89.6 | 49.9 | 13.2 | — |
| Fox carcasses | 43.4 | 19.2 | 20.7 | — |
| Horse-meat (average analysis from all trials) | 28.2 | 19.7 | 6.5 | — |
| Meat meal | 93.4 | 48.1 | 15.1 | — |
| Tomatoes, canned | 5.7 | 0.9 | 0.5 | 0.6 |
| Turnips, fresh | 9.3 | 1.6 | 0.5 | 0.9 |
| Whale meat | 32.4 | 26.9 | 3.6 | — |
| Adult ration containing raw cereal | 43.1 | 15.2 | 2.8 | 1.8 |
| Adult ration containing cooked cereal | 42.5 | 15.3 | 2.5 | 1.6 |
| Pup ration containing raw cereal | 41.0 | 13.4 | 5.8 | 1.4 |
| Pup ration containing cooked cereal | 42.4 | 13.4 | 6.8 | 1.4 |
| Hexite cereal fox meal | 89.8 | 14.3 | 4.4 | 4.2 |
| Hexite XX fox meal | 91.9 | 26.7 | 5.6 | 4.3 |
| Master pelting ration | 95.8 | 18.6 | 4.2 | 4 5 |
| Master breeding ration | 90.1 | 19.8 | 4.1 | 3.8 |
| Master fox puppy starter | 91.5 | 20.9 | 5.2 | 4.3 |
| Miracle cereal ration | 89.3 | 14.6 | 4.2 | 5.0 |
| Miracle fox meal | 89.4 | 27.3 | 5.5 | 4.4 |
| Purina fox chow | 87.9 | 25.9 | 4.5 | 4.5 |
| Ross-Miller standard cubes B | 87.6 | 19.0 | 4.7 | 3.7 |
| Ross-Miller kibblo | 91.9 | 19.1 | 0.9 | 2.4 |
| Ross-Miller fox crisps | 89.3 | 19.7 | 1.0 | 2.1 |

The analyses for dry matter, crude fat, and crude fibre were conducted according to the methods of the A.O.A.C. (1). The procedure for protein (N × 6.25) analysis was similar to the A.O.A.C., except that 50 ml. of 4 per cent boric acid were placed in the receiver and a standard sulphuric acid solution was used for titrating.

## RESULTS AND DISCUSSION

Table 1 shows the chemical compositions of the individual feeds and rations used in the digestibility trials, while Table 2 presents the average digestibility coefficients of these same foodstuffs. The coefficients of digestibility for horse-meat shown in Table 2 are the averages of 28 digestibility trials.

It will be noted that the digestibility coefficients of the protein of cabbage and carrots exceeded 100 per cent. This no doubt is accounted for by the fact that these two foodstuffs of low protein content were fed in combination with a high protein feed (horse-meat), and any slight variation in the digestibility of the protein of horse-meat would be greatly increased when the difference was transferred to the digestibility of the low protein feeds. This fact would also account for the low digestibility of the fat of Ross-Miller "Kibblo" and Ross-Miller "Fox Crisps."

TABLE 2.—DIGESTIBILITY COEFFICIENTS OF FOX FEEDS AND RATIONS AVAILABLE IN CANADA

| | Dry matter | Protein (N × 6.25) | Crude fat | Crude fibre |
|---|---|---|---|---|
| | % | % | % | % |
| Beef manifolds | 91 ± 1.0 | 93 ± 1.0 | 96 ± 0.1 | — |
| Blood meal | 55 ± 4.0 | 62 ± 4.0 | — | — |
| Bone, ground green | 41 ± 4.0 | 66 ± 4.0 | 99 ± 1.0 | — |
| Bone meal, steamed | 15 ± 6.0 | 40 ± 4.0 | 88 ± 6.0 | — |
| Cabbage, fresh | 74 ± 2.0 | 100 ± 8.0 | 50 ± 8.0 | 43 ± 5 |
| Carrots, fresh | 83 ± 3.0 | 104 ± 9.0 | 66 ± 5.0 | 32 ± 11 |
| Fish, frozen (Novascot fishblox) | 76 ± 5.0 | 95 ± 1.0 | 71 ± 4.0 | — |
| Fish meal (low fat) | 75 ± 2.0 | 91 ± 2.0 | 63 ± 7.0 | — |
| Fish meal (high fat) | 61 ± 3.0 | 69 ± 5.0 | 94 ± 1.0 | — |
| Fox carcasses | 84 ± 0.4 | 92 ± 1.0 | 99 ± 0.1 | — |
| Horse-meat | 94 ± 1.0 | 94 ± 1.0 | 97 ± 1.0 | — |
| Meat meal | 61 ± 5.0 | 80 ± 3.0 | 92 ± 2.0 | — |
| Tomatoes, canned | 81 ± 2.0 | 92 ± 9.0 | 45 ± 5.0 | 54 ± 6 |
| Turnips, fresh | 31 ± 6.0 | 69 ± 17.0 | 66 ± 5.0 | 33 ± 14 |
| Whale meat | 90 ± 2.0 | 97 ± 1.0 | 95 ± 2.0 | — |
| Adult ration containing raw cereal | 76 ± 1.0 | 87 ± 1.0 | 90 ± 1.0 | 15 ± 7 |
| Adult ration containing cooked cereal | 80 ± 1.0 | 83 ± 0.3 | 85 ± 1.0 | 16 ± 7 |
| Pup ration containing raw cereal | 66 ± 3.0 | 82 ± 2.0 | 92 ± 1.0 | 8 ± 7 |
| Pup ration containing cooked cereal | 70 ± 0.5 | 79 ± 1.0 | 93 ± 0.5 | 15 ± 6 |
| Hexite cereal fox meal | 74 ± 2.0 | 79 ± 3.0 | 75 ± 2.0 | 15 ± 8 |
| Hexite XX fox meal | 66 ± 2.0 | 80 ± 3.0 | 77 ± 2.0 | 24 ± 9 |
| Master pelting ration | 70 ± 4.0 | 73 ± 6.0 | 59 ± 6.0 | 20 ± 12 |
| Master breeding ration | 71 ± 6.0 | 82 ± 6.0 | 78 ± 3.0 | 7 ± 14 |
| Master fox puppy starter | 69 ± 2.0 | 81 ± 2.0 | 74 ± 2.0 | 19 ± 3 |
| Miracle cereal ration | 76 ± 6.0 | 85 ± 1.0 | 74 ± 8.0 | 6 ± 2 |
| Miracle fox meal | 73 ± 1.0 | 85 ± 2.0 | 79 ± 3.0 | 12 ± 4 |
| Purina fox chow | 71 ± 0.2 | 78 ± 0.2 | 74 ± 2.0 | 10 ± 6 |
| Ross-Miller standard cubes B | 71 ± 3.0 | 84 ± 3.0 | 74 ± 3.0 | 3 ± 3 |
| Ross-Miller kibblo | 84 ± 2.0 | 87 ± 2.0 | 1 ± 1.0 | 8 ± 8 |
| Ross-Miller fox crisps | 86 ± 2.0 | 88 ± 3.0 | 27 ± 10.0 | 21 ± 4 |

Cooking of the cereal portion of the adult fox ration and the pup ration increased the total digestibility of the rations by approximately 4 per cent. The cereal portion of these rations consisted of equal parts of rice, wheat, oats, barley and corn.

The digestibility of crude fibre was in general quite low, but was extremely variable.

## SUMMARY

The chemical analysis and coefficients of digestibility have been reported for 14 feeds, 4 complete rations, and 11 commercial fox feeds commonly fed by Canadian fox ranchers.

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